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CONTENTS SEPTEMBER 1951

SOME ASPECTS OF MODERN NAVAL AIRCRAFT DESIGN
D. L. Hollis Williams, B.Sc., F.R.Ae.S.

AIR TRAVEL—DISCUSSION

THE DERIVATION AND ESTIMATION OF AERODYNAMIC LOADS FOR STRESSING PURPOSES
D. J. Lambert, A.F.R.Ae.S. G.I.Mech.E.

NOSE WHEEL STEERING SYSTEMS
H. G. Conway, F.R.Ae.S.

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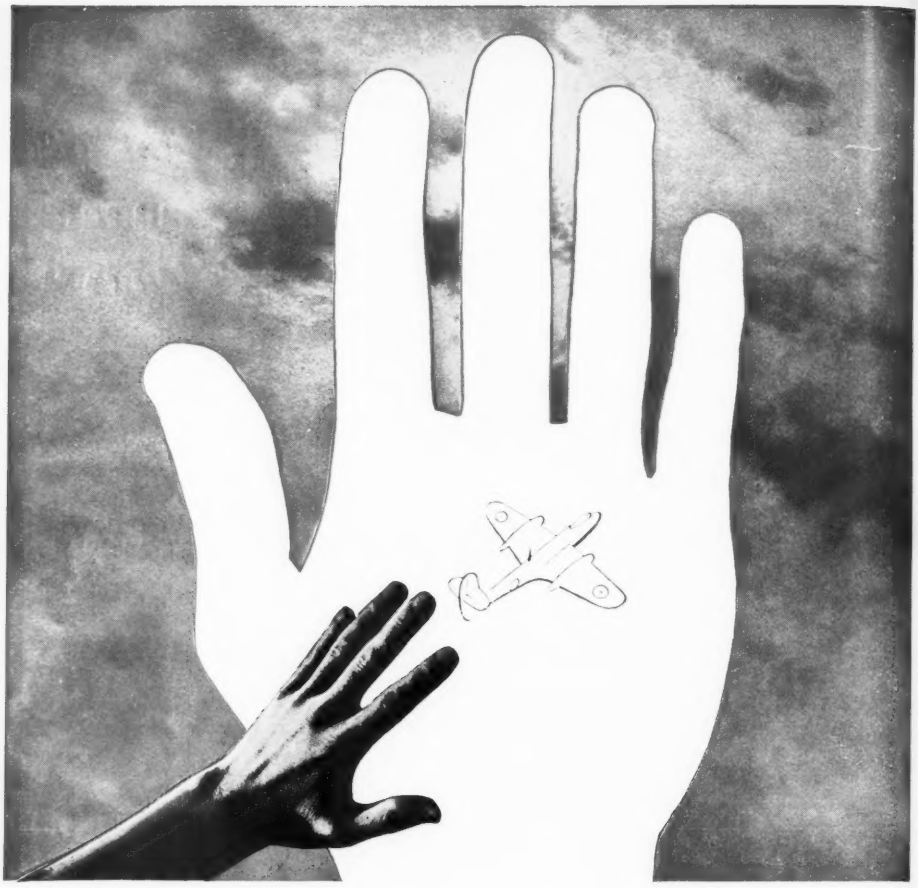

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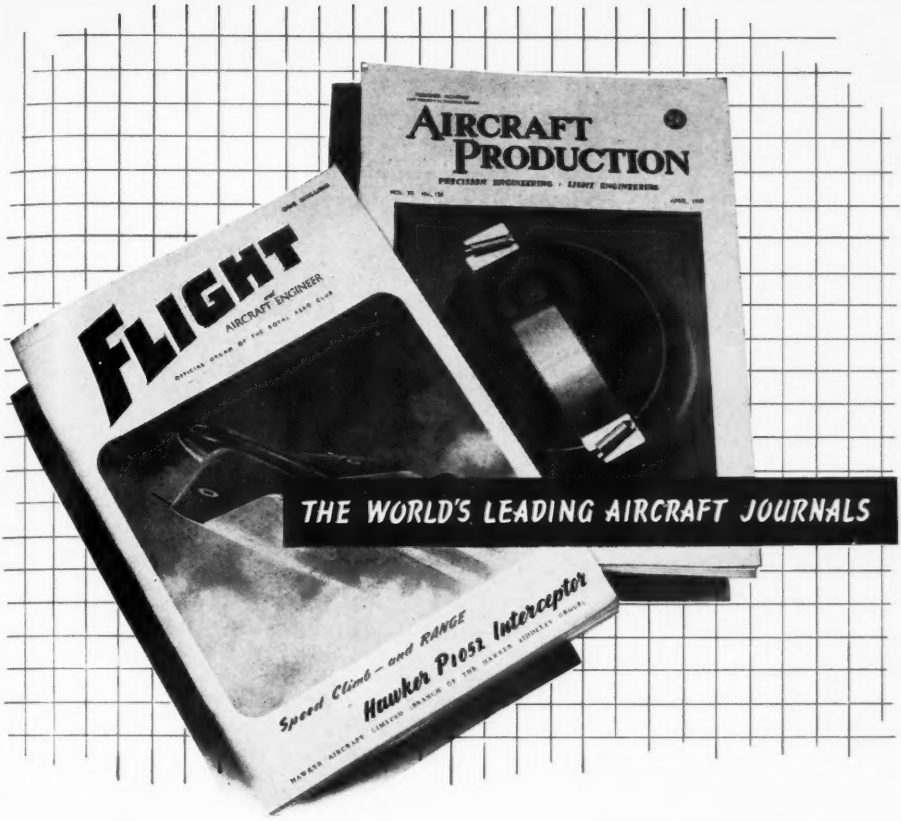

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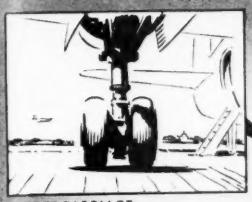

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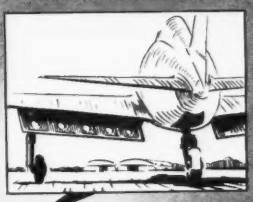

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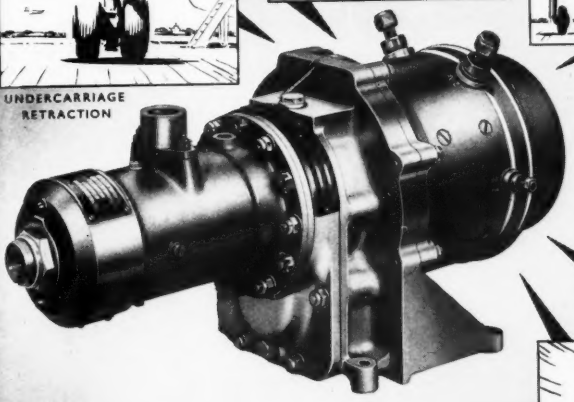

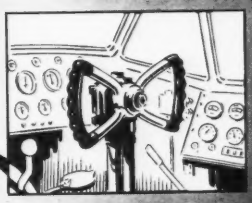

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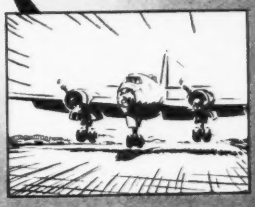

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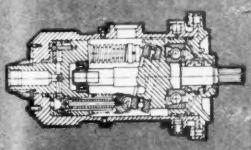

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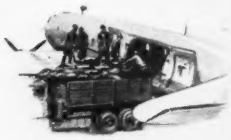

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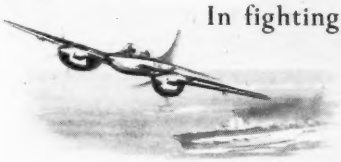

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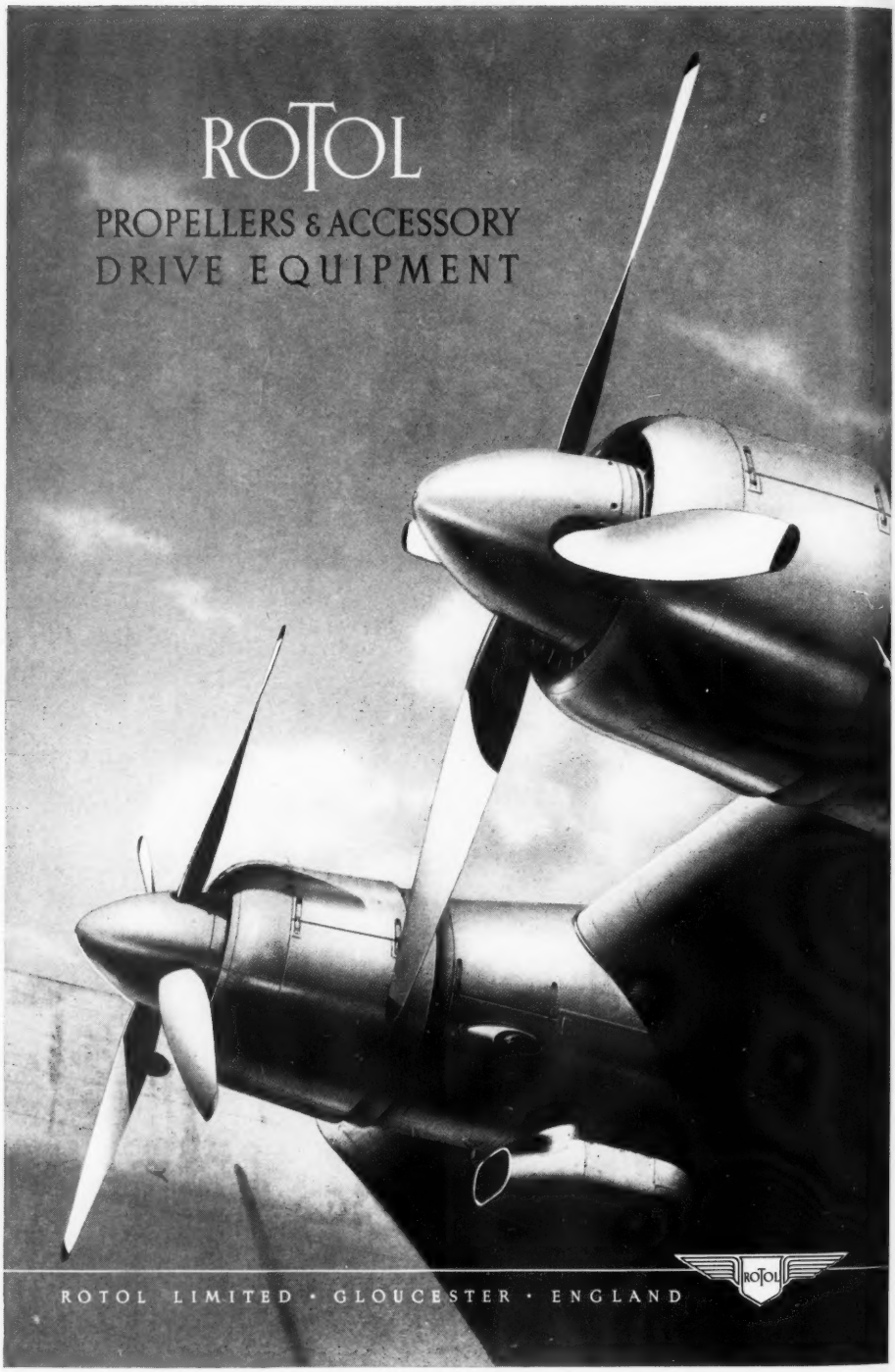
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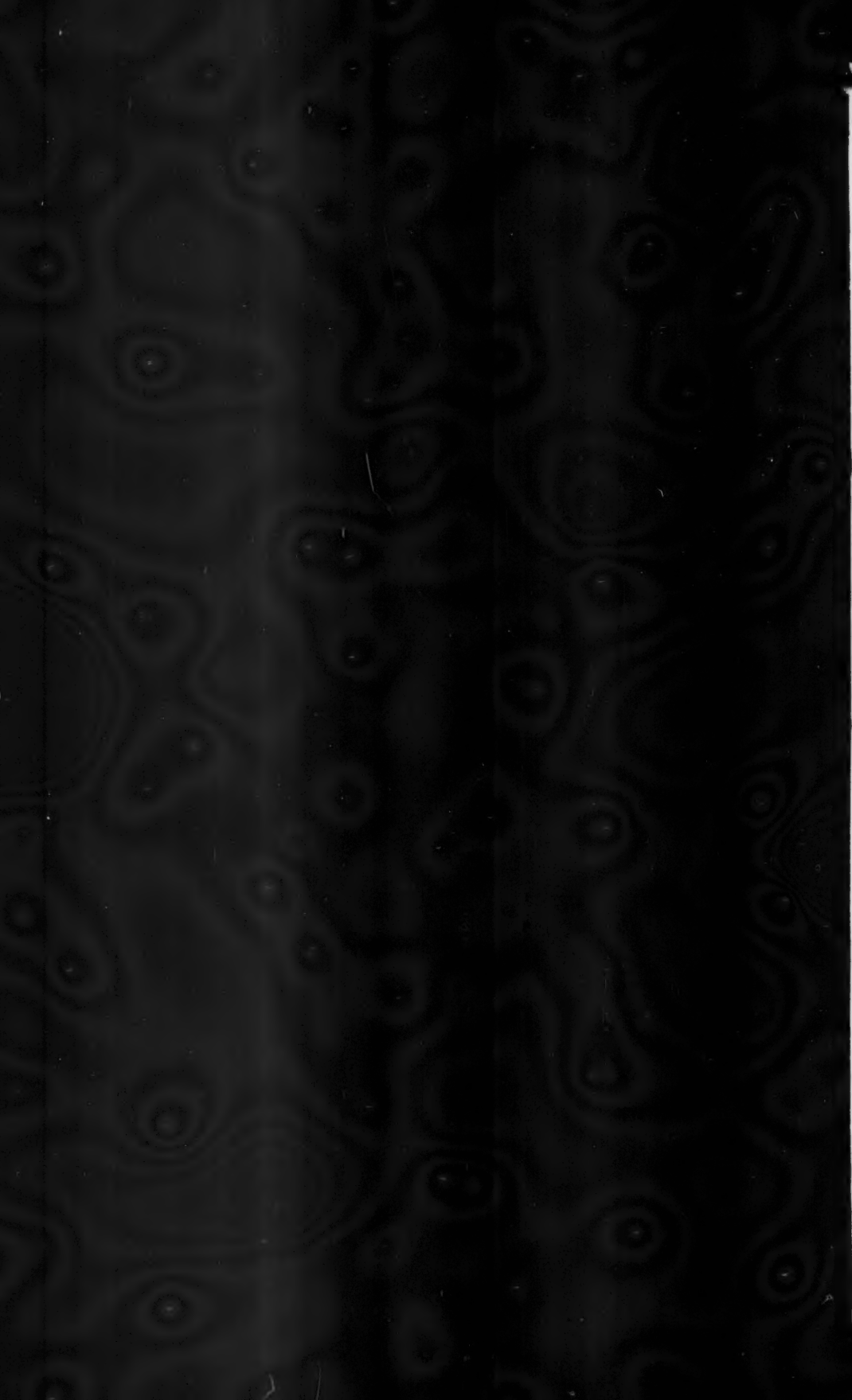

SOME ASPECTS OF MODERN NAVAL AIRCRAFT DESIGN

by

D. L. HOLLIS WILLIAMS, B.Sc., F.R.Ae.S.

The 823rd Lecture to be given before the Royal Aeronautical Society, "Some Aspects of Modern Naval Aircraft Design," by D. L. Hollis Williams, B.Sc., F.R.Ae.S., was delivered at the Institution of Civil Engineers, Great George Street, London, S.W.1, on the 29th March 1951. Major G. P. Bulman, C.B.E., F.R.Ae.S., President of the Society, presided at the meeting and introduced the lecturer, Mr. Hollis Williams, who had been engaged in the design of aircraft since 1927 and at the time of giving the lecture was Chief Engineer, Fairey Aviation Co. Ltd. He was awarded the Silver Medal of the Society in 1933 for the design of the Fairey Long-Range Monoplane.

INTRODUCTION

It is almost four years since a series of papers on Naval Aviation was presented to the Royal Aeronautical Society in the full day session held on 7th May 1947*. The first paper in that series, "Technical Problems of the Design of Naval Aircraft," read by W. S. Farren, stated the fundamental problems clearly.

During the intervening years, the general trends in aerodynamic and power plant development have been reflected in the design of carrier-borne aircraft and are beginning to stabilise into a recognisable pattern. Thus, turbo jet and turbo-propeller engines are now accepted for Service use, there has been general aerodynamic improvement including the suppression of drag arising from the carriage of stores, and it is normal to find that prototypes are mounted on a nose-wheel type undercarriage.

Service types are designed to Ministry of Supply specifications and even if a type originates as a firm's private venture, as soon as official interest is generated a specification is written around it. The specification summarises design conditions and operational requirements in general terms.

The aircraft designer's initial problem is to try to meet all these requirements in full. This is rarely possible and so preference must be given to those features which the designer considers of primary importance, at the expense of others. The design of an aircraft is almost always a compromise between a number of conflicting requirements.

The order of importance which the designer attaches to the various requirements can have far reaching results on the characteristics of the resulting aircraft. This explains why prototype aircraft designed and built by several firms to the same specification requirements may be very different in appearance (Figs. 1, 2 and 3). This is true for both shore-based and carrier-based aircraft, but in the latter case there are a number of problems which require special treatment and which recur on all naval types.

Naval operational aircraft can be divided into three groups:—

(1) Fighter group
(2) Strike group
(3) General Reconnaissance group with anti-submarine work as its primary role.

The whole subject cannot be covered adequately in one paper, in the limited time available, therefore certain sections have been selected for discussion which it is hoped will be of general interest. Since a large part of the author's time for the past few years has been devoted to the study of the Anti-Submarine problem, the main references in the paper will be to Group (3). This paper

*Journal R.Ae.S., October 1947.

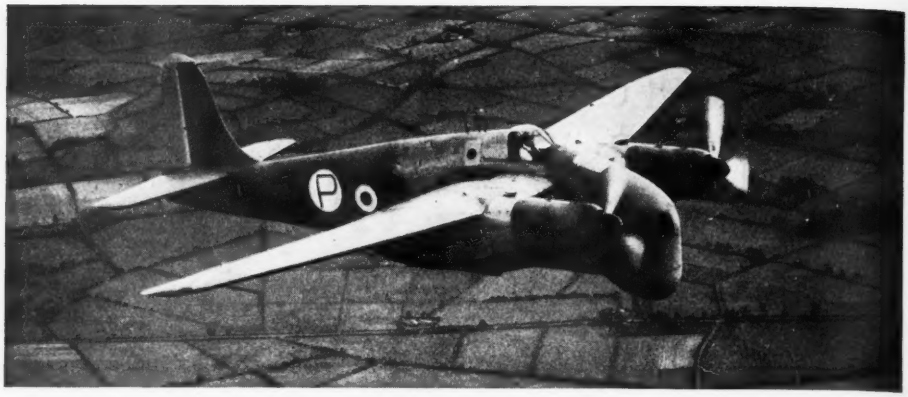

Fig. 1.
Short S.B.3 Anti-Submarine Aircraft.

on design policies and experience with one group of Naval aircraft is divided into three parts:—

(*a*) Problems which recur.
(*b*) The history of the development of a particular type of power plant for Naval application.
(*c*) Developments of Anti - Submarine aircraft.

PART I

PROBLEMS WHICH RECUR IN THE DESIGN OF ALL CARRIER-BORNE TYPES

Carrier-borne aircraft differ from their shore-based equivalents mainly because they are called upon to operate from the limited space available in an aircraft carrier. Design limitations, therefore, are imposed by deck take-off and landing, and handling and maintaining in confined spaces.

The carrier deck is divided into front and rear portions by a retractable crash barrier. The arrester wires are disposed athwartships across the after end of the deck and the catapults are in the forward portion of the deck. Under the flight deck is the hangar, a long uninterrupted corridor slightly narrower than the full beam of the ship, with a fair roof height—ashore it would be regarded as a large lofty hall. At each end of the hangar are the lifts used for transporting aircraft up on to the deck.

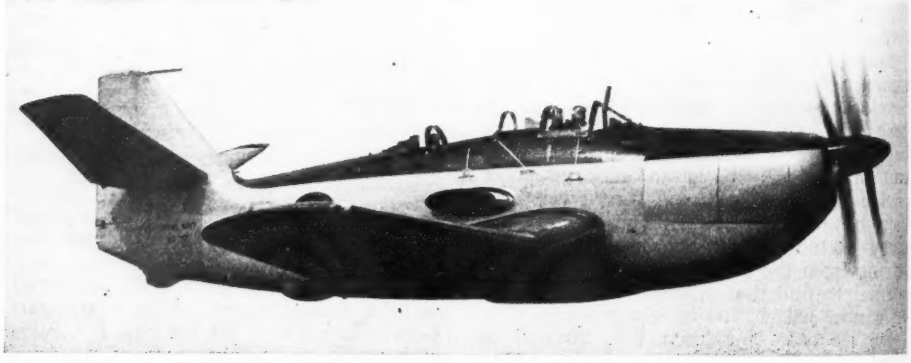

Fig. 2.
Blackburn Y.B.1 Anti-Submarine Aircraft.

HANDLING IN CONFINED SPACES

The problem is to stow as many aircraft as possible on the hangar floor space available, with the minimum of reserve space for maintenance and repair work, including change of engines, change of components and so on. The length of aircraft must not exceed the lift length and the folded width is dictated either by the width of the lift, or the need to stow so many rows abreast in the hangar.

Folded height is dictated by the height of the hangar roof, which is becoming fairly constant between the various classes of carrier. The closer the designer works to the limiting dimensions, the more time is taken up in handling and moving aircraft. Thus, if an aircraft is designed to the full length of the lift, it must be positioned accurately on the lift, all of which takes time and under operational conditions is a handicap. The carrier behaves as all ships do in rough weather: it pitches and it rolls and there must be enough clearance on limiting dimensions for an aircraft to rock on its shock absorber suspension without damaging itself on roof or walls.

THE TAKE-OFF SEQUENCE

(*a*) *Free take-off*

The free take-off applies mainly to aircraft in Group 3. The aircraft are brought up from the hangar and ranged up at the after end of the deck in tight park in the folded condition and engines are started up: meanwhile the carrier is turning into wind and working up speed to give the necessary air speed over the deck appropriate to the type. The leader moves out from the park and manœuvres on to the starting point: he rolls a few feet forward to straighten all wheels and then holds the aircraft on the brakes. The pilot selects wings "spread," checks that the operation is complete, lowers flaps to the take-off position and then opens up to full power, or as much power as the brakes will hold. On the signal "go," he releases brakes and takes off along the white line running along the deck, passing over the crash barrier which is lying flat on the deck.

(*b*) *Accelerated take-off*

The normal practice at the present time is to accelerate aircraft in Groups 1 and 2 off the deck. The accelerator consists of a long slot in the forward part of the deck through which projects a powerful forward-facing hook. The aircraft is taxied into position at the end of the slot. A cable connection is made between the aircraft and the accelerator hook with a tie-back cable at the after end of the aircraft to keep the system taut.

It is most important that the aircraft should have the right attitude on the catapult, with the wings at a positive angle of incidence approaching the airborne incidence.

The aircraft may have this incidence naturally built into the design, or it may have to be forced by ancillary means. The pilot selects wings spread, take-off flap, opens up to full power and sets himself to withstand the punch of the catapult. The catapult is fired, breaking the hold-back cable and at the end of the catapult stroke the pilot has a few feet of deck in which to

Fig. 3.
Fairey Gannet Anti-Submarine Aircraft.

rotate the aircraft to its full take-off incidence and is then away. This question of natural attitude on the catapult will be referred to later, as it is extremely important and governs the speed at which the ship must be driven to get the necessary wind speed over the deck and/or the accelerating force in the catapult.

(*c*) *Rocket assisted take-off*

It is usual to equip Naval aircraft for rocket assisted take-off, so that aircraft can be flown off when conditions do not permit free take-off, and without using the accelerator.

THE LANDING SEQUENCE

The landing sequence which is carried out so efficiently and accurately by Naval pilots appears to be a simple operation, but the apparent simplicity is only attained by continuous practice and repetition of the airfield dummy deck-landing technique ashore.

The aircraft, all set for landing, approaches the receding stern of the carrier from a beam to port. When within comfortable visual range, the pilot places himself under the signals of the deck-landing control officer. At constant height just above deck level, the pilot executes a turn into the turbulent air stream just aft of the carrier's deck. At a point in space, judged by the batsman, the "cut" is given, the pilot shuts off power, glides down on to the deck, flares out just before contact, and the arrester hook grabs a wire and decelerates the aircraft to rest.

The final motion of the aircraft is a slight recoil from the elasticity of the arrester cable which usually allows the pilot to retract his hook and drop the wire. Failing this, the deck crew rolls the aircraft back a few feet to release the wire. When the aircraft comes to rest, the crash barrier is lowered on to the deck, the pilot selects flaps up, the wings fold and he taxies across the crash barrier to the forward park. The crash barrier is raised immediately behind him and everything is set to receive the next aircraft, which is then probably just turning into the groove.

WAVE-OFF

Should the batsman decide at the last moment that the aircraft is not in the right position to pull off a successful deck landing, then he gives the wave-off and the aircraft must be able to accelerate to a comfortable circuit speed, which involves plenty of reserve power to check the sink and accelerate and, to avoid embarrassment to the pilot, the sudden increase of power on the wave-off signal should not be accompanied by violent changes of trim.

That is a short description of a series of operations which are carried out Navy fashion at express speed with perfect timing.

An analysis of these operations will show the need for special study of the following aircraft characteristics:—

(*i*) Adequate pilot's view

(*ii*) Good stability and control characteristics on the approach at speeds just above the stall

(*iii*) Immediate decay of thrust at the "cut"

(*iv*) Glide path characteristics

(*v*) Correct chassis characteristics to give:—

- Stability—wings folded in a rolling ship
- Correct attitude on the catapult
- Proper energy absorption on the landing
- Freedom from bounce and float

(*vi*) The arrester gear on the aircraft must be fully up to its job

(*vii*) Rapid wing spreading and folding.

VIEW

The first and foremost requirement on a Naval aircraft is that the pilot should have adequate view. The whole operation is simplified if a pilot can keep the whole deck in view during his approach and landing. The general improvement in the standard of view has enabled aircraft with very high closing speeds to be handled safely.

For years Navy pilots were landing aircraft on deck with no direct forward view and were only able to keep the batsman in sight by landing off a turn looking to port. Then aircraft came along with some attempt at forward view, but it was no uncommon thing for the centre panel of the windscreen to be partially obscured by a gun sight, so that the condition of one-sided view prevailed.

Later types of aircraft, now coming into service, have an unobstructed view which is obtained in some cases by mounting the equipment retractably, so that the panels of the windscreen are completely free from obstruction. It would seem that if a pilot has some 8 or 9 degrees of downward view,

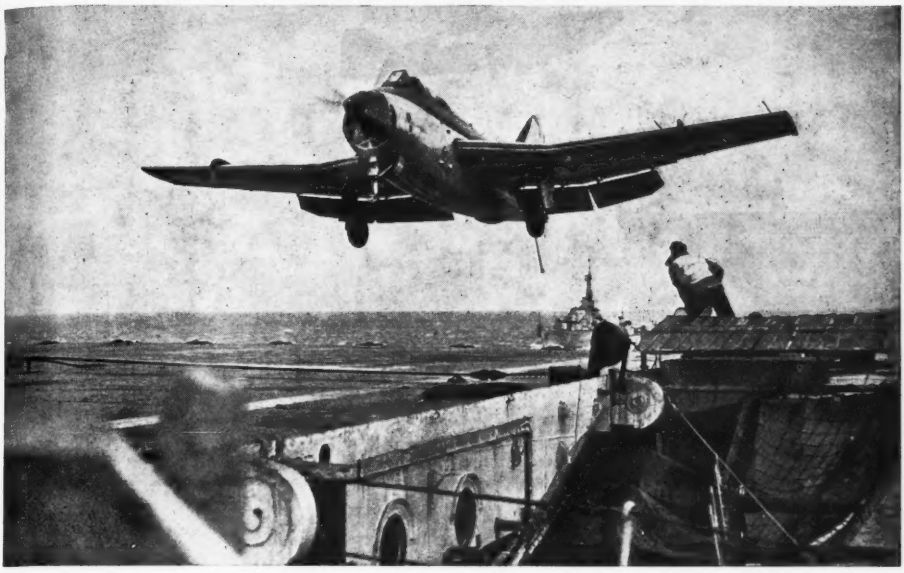

Fig. 4.
Gannet at the "cut."

measured from a datum parallel to the wing chord, he has all the view that is necessary for deck landing although other requirements, such as search and weapon sighting, may demand still greater angles of view.

Control and Stability

It is important that the pilot should be able to concentrate the whole of his attention upon the actual landing operation and should not have to jockey his aircraft. In recent years a continually increasing standard of control and stability has been demanded on acceptance trials to cover the condition of the approach and turn in for the deck landing. The advent of the nose wheel has played some part in contributing to the improvement of stability through its influence on the C.G. range of the aircraft, lending itself to a forward range giving greater margins.

In some cases control is reinforced by power boosting, but here again the question of manual reversion, which permits no lowering of the standing for slow speed approach, has to be considered. If an aircraft has a natural buffet as it approaches the stall, this is considered a good feature, but it is an extraordinarily difficult feature to design into the aircraft in the first place and still more difficult to reproduce on a production series.

Most carrier-borne aircraft nowadays have a subsidiary air speed indicator mounted up on the sight line and sufficiently far from the pilot's eye, so that he can keep it under observation without changing focus.

Decay of Thrust

The piston-engined type of power plant had very satisfactory characteristics for deck landing work. On the "cut" the response to closing the throttle was immediate and the loss of slipstream velocity over the wing promoted the right sort of conditions for the sink on to the deck.

The advent of the jet and the propeller-turbine has introduced a different set of circumstances and there is a tendency for the thrust to persist after the "cut." This condition has required special treatment in the case of the propeller-turbine.

Glide Path after the "Cut"

The glide path after the "cut" (Fig. 4) can be either flat or steep, depending on aerodynamic variations designed into the aircraft.

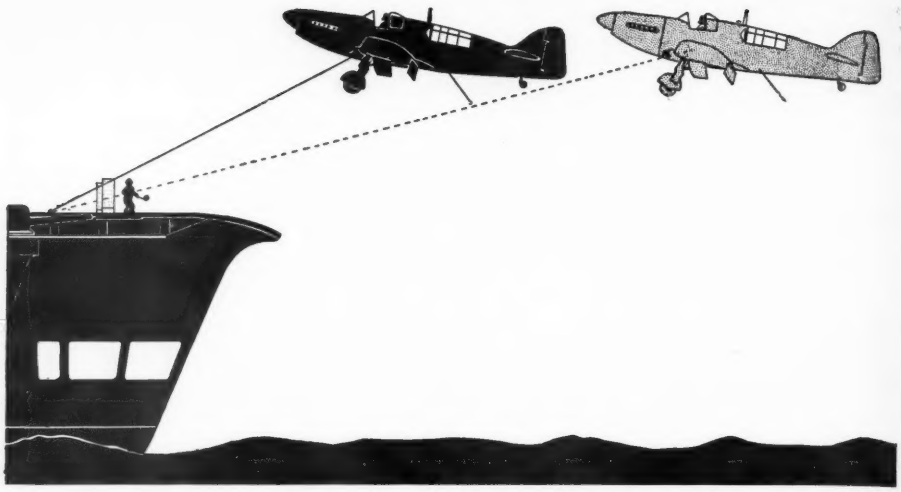

Fig. 5.
Illustrating effect of flat and steep glide path.

To achieve a flare out just before contact with the deck, excess lift is required, which means that the glide-in speed must have a margin in hand over the engine-off stalling speed.

The steeper the glide, the greater the excess lift and consequently, the faster the glide speed. If the flare out is not made accurately, then the chassis shock absorber system is called into play. If the gliding angle is sufficiently steep to load up the shock absorbing mechanism to its design conditions, trouble must be expected over a period of operations.

From the designer's point of view, the flat glide is the most attractive as it permits the slowest approach and the easiest conditions for the flare out, without too much demand being made on the shock absorbing capacity in the event of error of judgment. It means, however, that the "cut" must be given at a point in space some distance aft of the carrier stern, which is more difficult for the batsman to judge even under calm conditions and makes a wave off more likely under rough sea conditions. From the pilot's and the batsman's point of view, it is preferable to have a steep glide path after the "cut," so that the "cut" can be given close up to the stern and the pitching of the deck is less likely to interfere with the landing (Fig. 5).

The designer has to make the important decision as to how far he goes in one direction or the other, as this one feature can go a long way towards making or marring the popularity of the type.

The great thing is to build plenty of controllable drag into the flap system and then this can be balanced during flight test development by adjustments to residual thrust.

Chassis characteristics

The tail wheel type of undercarriage had many natural advantages for Naval aircraft. This is realised only after the same problems for a nose wheel aircraft have been solved.

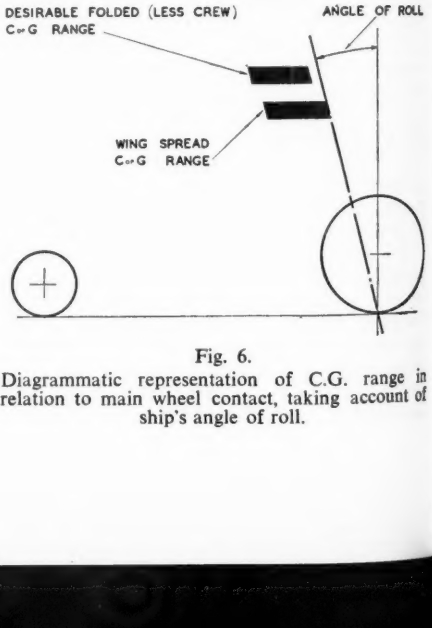

Fig. 6.
Diagrammatic representation of C.G. range in relation to main wheel contact, taking account of ship's angle of roll.

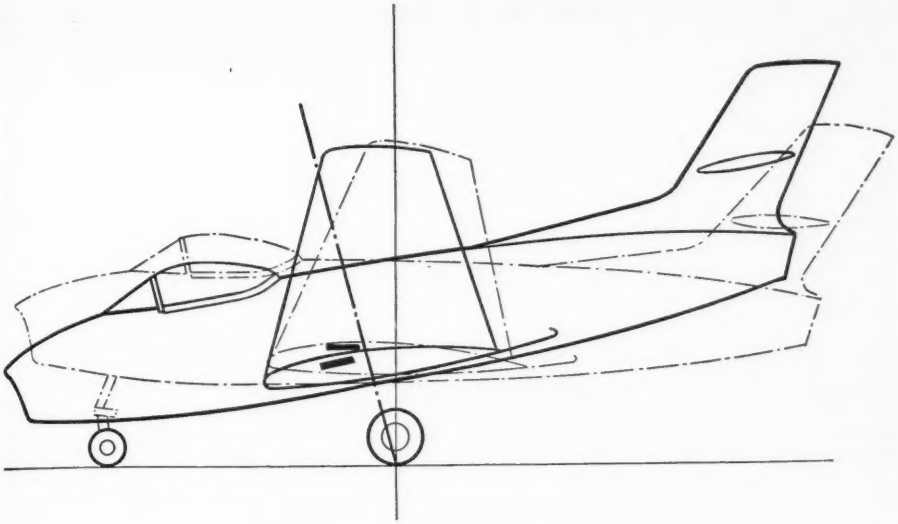

Fig. 7.
Diagram showing effect of " kneeling " action giving stability against ship's angle of roll.

The stability of a tail wheel aircraft in a rolling ship, especially with backward wing fold, was excellent. Towing ahead or astern was simple and controllable. There was no need to worry about the dynamic motion of the aircraft on its shock absorber system and because of the long wheel base, there were no important magnifications of movement. The attitude on the catapult was naturally correct and folded height was less of a problem.

The tail wheel aircraft was reasonably good directionally for take-off on deck. It was only the landing that required a certain accuracy of speed and attitude. In the event of a misjudged landing, leading to bounce and float over the wires, the aircraft was usually gathered up safely by the crash barrier.

The theory underlying the change over from tail wheel to nose wheel is that a first contact with the deck, ahead of the C.G. of the aircraft, promotes an increasing wing incidence with tendency to bounce and float, whereas the first contact aft of the C.G. promotes a decrease in incidence, reduces lift, and so reduces the tendency to bounce and float. The nose wheel undercarriage is primarily a device for reducing lift at the moment of contact, but it has other advantages and some disadvantages. Some aerodynamic device for destroying the lift on a tail wheel undercarriage may eventually prove to be the right way of retaining the advantages and avoiding the disadvantages.

The design of a nose wheel type undercarriage for a shore-based aircraft is relatively simple. The pilot should be able to rotate the aircraft about its main wheels progressively during the take-off and this condition is achieved if the main wheels are positioned just aft of the farthermost back position of the C.G. The only over-riding condition is that non-flight conditions of loading should not allow the aircraft to tip back on to its tail bumper, which is rather unpleasant, especially with a large aircraft.

A Naval aircraft may be stowed athwartships, or it may be in a tight park on deck with its tail hanging over the side. It is essential that the aircraft should have stability on its nose wheel undercarriage up to the maximum angle of roll of the ship, which may be as much as 20°. The stability on the undercarriage is mainly important in the folded condition, as the aircraft is never likely to be athwartships with wings spread.

An angle between the point of contact of the main wheels and the aftermost position of the centre of gravity, measured from the

vertical sufficiently large to cover the full roll of the carrier may be too great for comfortable rotation during the take-off, and the lifting of the nose at forward positions of the centre of gravity is likely to be even more difficult (Fig. 6).

This points the way to the exercise of ingenuity in throwing the centre of gravity forward in the folded condition. This can be achieved by either a forward component on the wing fold or, on jet aircraft, by a sort of "kneeling" position of the nose wheel (Fig. 7). Because the base of the nose wheel undercarriage is relatively short, there is magnification of movement at the tail end. If the nose wheel oleo has spongey characteristics, a sudden check by brakes or chocks when moving the aircraft in the hangar may increase the height of the tail by an amount proportional to the compression of the nose oleo. This point must be watched carefully during design, especially if the designer is working close up to roof height dimensions.

There has been some suggestion that a four-wheeled undercarriage may be the right answer and this may be so, provided that the aircraft is stabilised positively one way or the other in the folded condition. An aircraft which just rocks about its main wheels either on to a nose wheel or a tail wheel in sympathy with the motion of a ship, would impose an unacceptable limitation on parking arrangements.

The nose wheel undercarriage introduces problems on the catapult. It is desirable to cater for the catapult condition under normal static attitude of the aircraft. The aircraft should sit naturally on the ground with its wings at a positive angle of incidence and its tail well down: in fact, almost in a landing attitude. If the aircraft has a zero incidence attitude, then a forced attitude will be required on the catapult, which may require ancillary equipment and which, in any case, means the loss of valuable seconds in loading and firing.

Nose wheel aircraft tend to be landed more heavily than tail wheel aircraft, as the landing operation is not so critical to speed and attitude.

It is particularly important with nose wheel undercarriages to be sure that the shock absorbing capacity is there, and for Naval aircraft, it is most important that the recoil be well damped.

It is possible for a nose wheel aircraft to come clear off the deck under sheer recoil and, if this is possible, then the arrester gear must be sufficiently long to retain contact with the deck.

Arrester gear

The development of suitable arrester gear is mainly a case of hammering on the test bench. The aircraft arrester gear, sting or frame type, with attachments, must be able to stand repeated loading without fatigue. The damper gear must be completely reliable to ensure that the hook is pressed down on the deck without bounce. It must follow the deck, whatever the motion of the aircraft, until it has picked up a wire. Faulty damper gear can be responsible for barrier crashes.

At present sting-type arresters are in favour, but perhaps at times a pilot would prefer his arrester hook to be not quite so far behind his sight line, as on a large aircraft he progresses well on towards the crash barrier before feeling the satisfying drag of the arrester cable.

Wing folding

The operation of folding and spreading must be quick to avoid delay in operations. The system of wing folding adopted should help to stabilise the aircraft on its undercarriage under rough sea conditions.

In the event of power folding failure, an alternative scheme for manhandling the wings into the folded position must be readily available to avoid putting the deck out of action. This also applies when the aircraft is damaged, which may be a chassis collapse, letting the wing down on to the deck: thus access to wing emergency fold should take care of this condition.

PART II

NAVAL POWER PLANT

It has been normal practice to design Naval aircraft around military engines, designed initially to Royal Air Force requirements for shore-based aircraft. In fact, many successful carrier-borne types, mainly in the Fighter group, have been derived or converted from Royal Air Force types. It would appear, therefore, that there is no requirement for a power plant designed specifically for Naval use.

Over a period of years, there have been attempts to design specifically for Naval application but, for a variety of reasons, until

recently such efforts have never come to fruition. It is proposed, for general interest, to consider some of this past history as, if it does nothing else, it does give an idea of the time that some ideas take to germinate.

In the period between the wars as engine power increased, a number of attempts were made to break down the total power into self-contained units so that failure of one small accessory would not lead to total power failure. The Bugatti multi-engine, the Fiat and Hispano double engines and the small double Menasco are remembered, and there may be other attempts on similar lines.

In the early 1930's the increase in engine power that was becoming available meant complementary increase in propeller diameter and for Naval aircraft this was rapidly becoming a design limitation, due to the low height of the carrier hangar roofs then available. The stage had been reached where, with multi-bladed propellers, it was necessary to position carefully the propeller before the folded aircraft could be moved in under the hangar roof.

The Fairey Aviation Company, therefore, had started to think seriously about designing and building contra-rotating propellers for use with the big power single engines then becoming available, with a view to reducing overall propeller diameter and opening up the way for still more powerful engines.

As range and performance increased, making it possible for aircraft to operate hundreds of miles away from their carrier

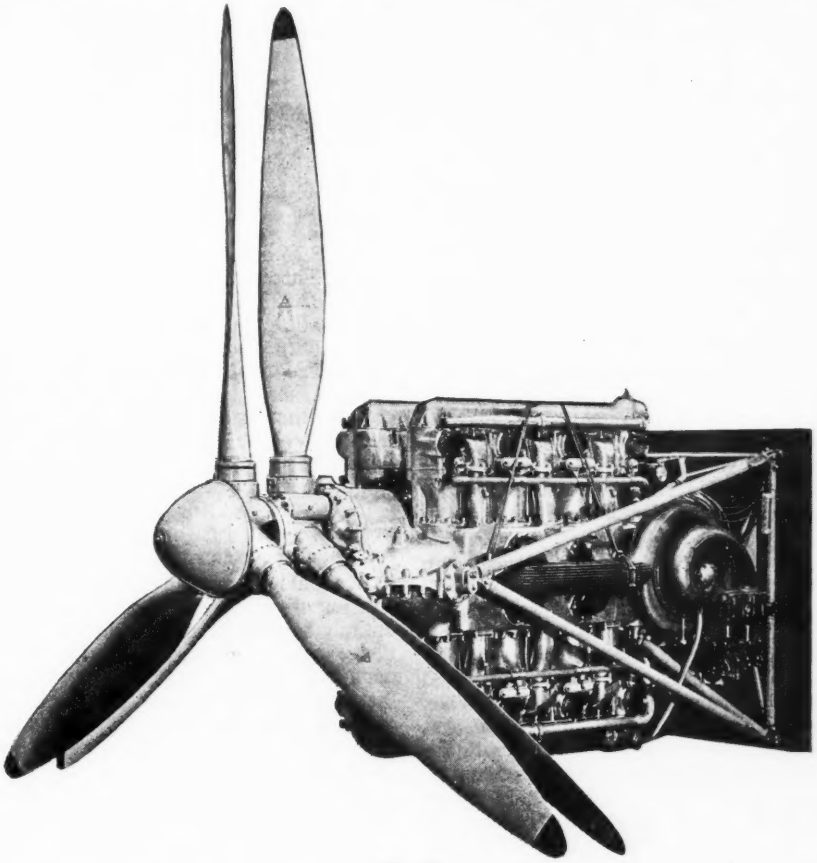

Fig. 8.
Fairey P.24 double engine.

Fig. 9.
Fairey P.24 engine installed in Battle aircraft.

bases, the Company had the conviction that everything possible should be done to save the percentage loss that was bound to occur of valuable crews, equipment and aircraft, which led to the idea of duplicated power.

Permissible folding dimensions were then of the order of 13 ft. and it was not possible to design an aircraft with twin engine nacelles mounted on the wings, which would fold into such limited dimensions, even if the aircraft could be handled safely on one engine for an emergency deck landing.

In 1935, A. G. Forsyth, the Fairey Engine Designer, proposed a double engine with each power unit completely self-contained and each unit delivering its power through one half of a co-axial propeller. This double engine, the P.24, and co-axial propeller combination was ordered and then designed and built by the Fairey Company (Fig. 8). When cleared for prototype flight testing, it was mounted in a test bed "Battle" aircraft. By that time it was 1939. Under pressure of war, the decision was taken not to go ahead with production in Great Britain, but the P.24 "Battle" was shipped out to America for assessment at Wright Field and created a profound impression (Fig. 9).

The P.24 engine comprised two 1,000 h.p. units. There were in America at that time several 2,000 h.p. engines, so steps were taken to develop the P.24 up to the 3,000 h.p. class with a view to installing it in an operational fighter. History repeated itself, however, and the shock of Pearl Harbour caused the emphasis to be transferred immediately to the mass production of developed engines and the P.24 project was again shelved. Nevertheless, it was an extremely promising venture and was probably the first engine designed specifically for Naval requirements.

It should be said in this connection that the initiative for twin engine safety came entirely from the Fairey Aviation Company. There was no pressure from the Navy for such a development. The morale of the Naval pilots was then, as it is now, entirely proof against the prospect of an occasional ditching, which seems to be accepted as part of the normal day's work.

During the war years, developments in connection with this line of thought were in abeyance until 1944 when the problem received some attention from a different angle. The Company was anxious to pack

more power into one of its types, and H. E. Chaplin proposed a scheme based on two Merlin engines, in tandem formation, with shaft drives to a special gear box, mounting a co-axial propeller. This development was ordered and work was started, but was not completed because of the advent of jet and propeller-turbines which it seemed would provide the answer in a simpler fashion.

Towards the end of the 1939-45 War the Company was working on a projected Naval strike aircraft based on a propeller-turbine engine and difficulty was found in meeting the fuel load requirements, both from a point of view of stowage and the effect on total weight.

It was realised that here was the outstanding reason for reverting to the double engine. The study of a typical turbine power consumption curve showed that the specific consumption rose rapidly with throttling and that it paid to operate the engine at, or near, full load. Thus, with the power broken down into two independent units, it would pay to operate one unit close to full load with the other shut down, under cruising conditions.

Discussions were held with Rolls-Royce and a double power plant was schemed, based on two large propeller-turbines. The type was ordered and a considerable amount of design work, and some manufacture, was done over a period of some 18 months. The engine development programme at that time, however, was so over-loaded that some items had to be deleted and unfortunately this double engine was thought to be of limited application and so it was stopped, which brought the aircraft project to a standstill.

When the specialised anti - submarine requirement materialised, it was seen that the same arguments would apply. The choice of engine for a new prototype is the most difficult and dangerous single decision which the aircraft designer has to make. It is generally considered unwise to associate a prototype engine with a prototype aircraft, although recent rapid developments in turbines have often made such a risk unavoidable. The wise designer also leaves himself a loophole. If one experimental engine fails to be ready on time, then it is a great mental relief to have an alternative engine which can be fitted into the aeroplane.

For the Fighter Group, the jet turbine offers such overwhelming advantages that the choice has only to be made between the relative merits of the various jets available. In the Strike Group, the decision may rest with either the pure jet or the propeller turbine.

In the Anti-Submarine Group with its free take-off requirement, the choice falls between the piston engine and the propeller-turbine. At about 3½ hours' endurance, with allowances for warming up, take-off, climb and stand-off, and so forth, the twin propeller-turbine, plus fuel load, balances the weight of the single piston engine plus its fuel load. From 4-6 hours' endurance, the weight of the piston engine plus fuel is lighter than the weight of the twin propeller turbine plus fuel. For endurances of more than 6 hours, it pays on a weight basis to compound the piston engine. The piston engine requires high octane fuel and is handicapped by the requirement for flame damping which adds weight and reduces power, which extends the endurance time slightly to the cross-over point, but the balance is sufficiently close to make decision difficult.

Had there been a piston engine of just the right size with a margin in hand for development, it is probable that the Fairey Company would have made a conservative selection in favour of the piston engine. As it happened, the only piston engine available in the weight/power class required held out no particular promise for future increase of power and, although it would have satisfied performance requirements for the anti-submarine type, at its starting weight, it was known from experience that all Naval types increase by at least 20 per cent in all-up weight during their life (the Swordfish operated at 40 per cent overload), and it was necessary therefore to choose an engine, or engines, which had sufficient reserve to cope with this probable final weight.

The Company was attracted to the "Mamba" propeller-turbine, which was of small dimensions because of its axial flow compressor, and it had already reached quite an interesting stage in its development. It was proposed to Armstrong Siddeley that two of these engines should be coupled to form a power plant, and the full support of that Company was secured.

There was some doubt as to whether the right way to develop the thrust was through a contra-rotating propeller or a co-axial propeller. The contra-rotating propeller meant a system of clutches and free wheels and introduced various unknown features,

Fig. 10.
Gannet engaged in dummy attack.

whereas Faireys had had flight experience with the co-axial and were satisfied that no unpleasant surprises would result from such a development. Therefore the Company encouraged Armstrong Siddeley to go ahead with the co-axial arrangement and stressed the importance of retaining complete independence of power units. The engine as designed and developed has complete independence of gear trains, and so on, with separate lubrication systems: the only point at which there is dependence is where the co-axial shafts rotate one within the other.

The development turbines have given an extraordinarily good account of themselves, with long periods of maintenance - free running. At the present time they are sensitive to starting up conditions, either on the ground or in the air, and a false start will give a rapid temperature rise which may cause trouble. This will mean further development and the introduction of automatic means to avoid such critical conditions.

During the development flight testing period of the prototypes it has been a great advantage to have the twin arrangement, and prototypes have been brought home with one turbine shut down, which otherwise might have been damaged in a forced landing.

The great virtue of the double engine for Naval application is that all the power is on the centre line of the aircraft. With the increased folded dimensions permitted in the larger modern carriers, it is possible to design with engine nacelles on the wings, and it is possible to provide aerodynamic arrangements and control which enable such an aircraft to be handled on one engine.

Deck landing on one engine with a conventional twin must always involve difficult handling problems for the pilot, whereas with the double engine, operating on one engine is normal and provided that the one engine has sufficient power to give the slow speed engine-on approach, deck landing on one engine is no longer in the emergency category.

Turbines have solved the flame damping problem, which was a perpetual nuisance

with the reciprocating engine. Already side-line advantages are showing up which weigh the balance in favour of the turbine. Noise level tends to be low, which increases the efficiency of radio and intercommunication work. Vibration tends to be low, which improves the serviceability of instruments, radar and radio equipment and, since this group of electrical equipment tends to give the highest percentage of unserviceability, that is a tremendous achievement.

Both jet and propeller-turbines give great flexibility in the choice of fuels and although more fuel is burnt, the absence of high octane petrol does simplify the storage problem for the carrier.

PART III

THE DEVELOPMENT OF AN ANTI-SUBMARINE TYPE

In the First World War Anti-Submarine operations, so far as aircraft were concerned, were mainly restricted to attacks by bomb and machine gun on targets as opportunity presented, such as surfaced submarines or submarines travelling at periscope depth in water conditions which enabled visual contact to be made. Between the wars, progress in this vital work was mainly confined to the development of special anti - submarine bombs and mines.

At the start of the Second World War, the Swordfish was the operational aircraft for carrier anti-submarine operations, and the first specialised item of anti - submarine equipment, apart from droppable stores, was the Leigh light mounted under the lower wing, by which it was hoped to surprise surfaced enemy submarines at night. This in turn was followed by the fitment of radar sets for detecting the quarry, and in due course the strike was augmented by rockets, and other devices.

In all the aircraft used the Anti-Submarine role was subsidiary and was not the primary role for which the aircraft had been designed. Towards the end of the war, and during subsequent years, important developments have taken place in both search and strike equipment, and it remained to produce a specialised aircraft to make the best use of these developments.

It is proposed to deal now with some points of technical interest which have arisen during the course of one solution to this problem: the Fairey Gannet combined search and strike anti-submarine aircraft. In the introductory remarks it was said that all aircraft design was a compromise between a number of conflicting requirements, all apparently of equal importance, but this particular type is remarkable for the small degree of compromise (Fig. 10).

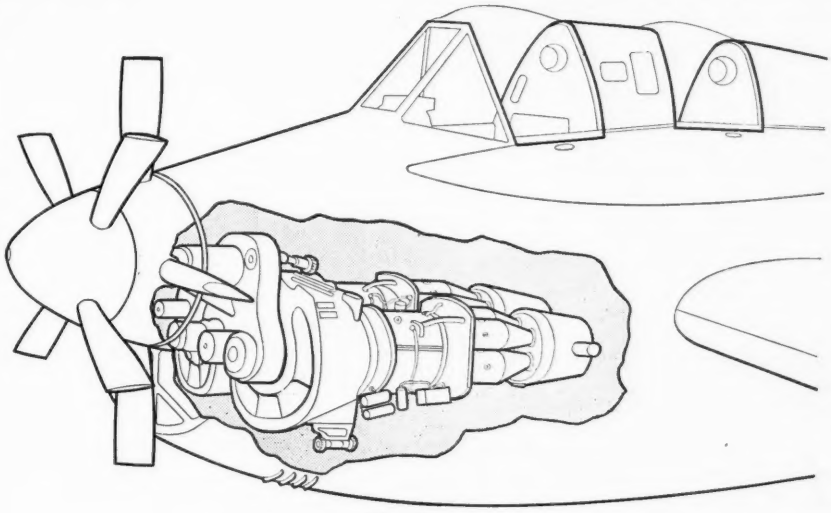

Fig. 11.
Diagram of Double Mamba in cut-away nose of aircraft.

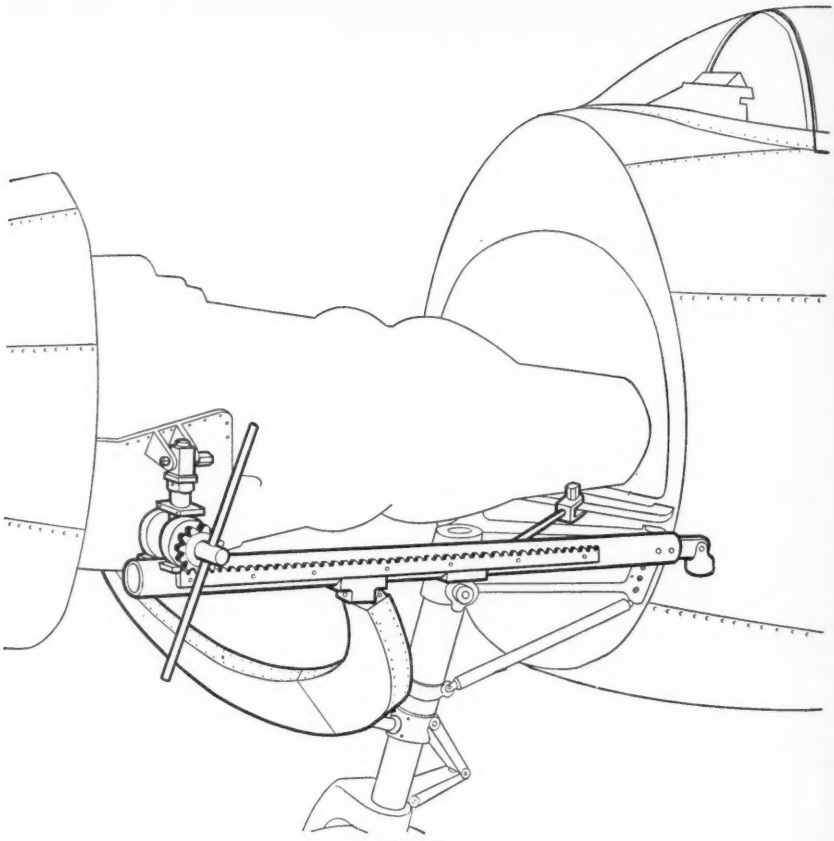

Fig. 12.
Diagram showing withdrawal scheme for the Double Mamba.

The starting point was the decision to use a double power plant based on two single Mamba propeller-turbine units. The engine designers agreed to design around any geometrical arrangement of engines, gear box and propeller shafts that were required if it were practical and possible. Thus the Company was in the unusual position of being able to prescribe what virtually amounted to a tailor-made engine and to work this up in conjunction with pilot's cockpit and angles of view (Fig. 11).

There was thus no compromise on pilot's view and there was certainly no compromise possible on power plant. Had the double Mamba failed to appear on time, no other engine or engines could have been substituted, short of a complete redesign forward of the front spar. It was only the profound conviction that the solution proposed was right, in view of previous experience with the P.24, which made the Company take this risk to get the 100 per cent. solution. The picture looked fairly gloomy at times while the engine development team was struggling with the usual development troubles, but the first unit arrived in time for the aircraft which, as is usually the case, was also late as a result of its own particular problems on final assembly.

Jets and propeller-turbines have already gained a reputation for requiring little maintenance and this was exploited to the full by installing the engines in a tunnel under the pilot's cockpit floor with a slight compromise on accessibility. It was obvious that from

time to time full access would be required so a scheme was evolved for rapid extraction of the power plant.

The double Mamba power plant is provided with a front pair of detachable rollers and a rear pair of rollers permanently mounted. The rear rollers rest on rails built into the structure. For power plant removal, a pair of ancillary guide rails are attached at their rear ends to the bulkhead and the forward ends of the guide rails are mounted on a large ancillary supporting bracket which, in turn, is anchored on the fixed part of the nose wheel shock absorber (Fig. 12).

The engine gear box has cast lugs which receive the front pair of rollers and by means of a hand-operated ratchet, the whole power plant can then be run forward once the connections have been cast off. This scheme has the virture that it is self-contained on the aircraft: the ancillary gear is light and small enough to be carried in the aircraft and the operation is independent of shock absorber compression, so that the aircraft does not have to be jacked up and trestled. It is only if the power plant has to be lifted from the guide rails that a prop is necessary under the tail of the aircraft.

The one slight compromise was on the positioning of the radar set. The perfect position is right at the front of the aircraft below the nose, which gives a completely uninterrupted forward scan, but this can only be achieved with a conventional twin.

The solution on this particular aircraft was to mount it at the rear end of the bomb bay on a retractable mounting, making sure that the attitude of the aircraft under cruising search conditions gave an almost uninterrupted scanner presentation picture.

The aerodynamic design of the aircraft with regard to wing areas, tail volumes, and so on, was based on the continuous rating of one turbine. To keep down the folded height and to give stability when stowed, a double wing fold is used, with a view to keeping the folded C. of G. of the aircraft as low as possible (Fig. 13). As a contribution towards aerodynamic cleanness, a suppressed flap hinge system is used for the first time on Fairey aircraft, thus avoiding the exposed flap hinges which have been a feature of all earlier Fairey types. The low position of the tail in the "standing" attitude gives ample margin on hangar roof clearance for any emergency such as a collapsed nose oleo, or simply through the dynamic effects of sudden check when the aircraft is being rolled into position in the hangar.

It will be noted in the side view of the aircraft in its normal static position that the aircraft is mounted on its chassis at a positive

Fig. 13.
Gannet double wing fold.

angle of incidence—in fact, almost at the landing attitude. The object of this was to favour catapulting conditions, so that the aircraft at the end of its stroke will be very nearly at the appropriate incidence for flight without artificial aids (Fig. 14). Such a nose up, tail down attitude has to be considered in relation to the landing operation. It will be realised that such an attitude brings the nose wheel into action during the course of a normal landing much earlier than is customary on nose wheel undercarriages, which it is suggested is a good feature, if not overdone. Thus, the aircraft has little opportunity to acquire angular momentum on the pitch forward and there is a speed or attitude at which it will do an actual three-pointer.

There is thus a general tendency to spread the load on to all three shock absorbers, giving a very useful reserve margin of shock absorption and strength. If this nose up attitude is overdone, it means that with excess speed or a last minute nose down change of attitude, the condition of first contact forward of the C.G. will arise, and so a correct judgment must be made as to how far it is safe to go in this direction.

The actual design of the nose wheel deserves some comment. The twin nose wheel arrangement was governed by the space available in the retracted stowage. Geometrical limitations made it impossible to provide a vertical nose oleo which would have led to a simple castoring bearing in its base. Experiments with the nose and tail towing of models showed that the angle of this castor bearing was critical and so an offset castor bearing had to be provided at the bottom end of the oleo.

One problem was to avoid nose wheel shimmy and to arrange a free castor for slow speed handling, manœuvring and towing. The solution used, limits the freedom of the castor for take-off, landing and retraction, and then frees it for slow speed handling.

The strength of the airframe structure was obtained by mechanical test development. Some years ago the Company was required to increase the load factors of one of its types by some 10 per cent. It seemed that it would be a formidable task. The strength of this type had been arrived at by calculation and then the completed aircraft was put up for test and carried the design load successfully. When the computation of the effect of the increased factor was completed, to the author's amazement he found that a very short list of modifications would give the desired improvement. The whole structure, in fact, was much stronger than it need have been, apart from these few items which had been designed right down to calculated loads.

For the Fairey Gannet, therefore, it was decided to develop the required strength by actual testing. The method by which this was achieved was to base the strength calculations on an early weight estimate and then take no account of the fluctuations in total weight which occur during the design of any aircraft.

The airframe was finally put up for structural test with a load distribution based on the actual total weight which the finished aircraft would have. During the course of these tests a few local points had to be strengthened, but in due course the airframe was cleared without undue difficulty, and with very satisfactory results so far as structure weight was concerned.

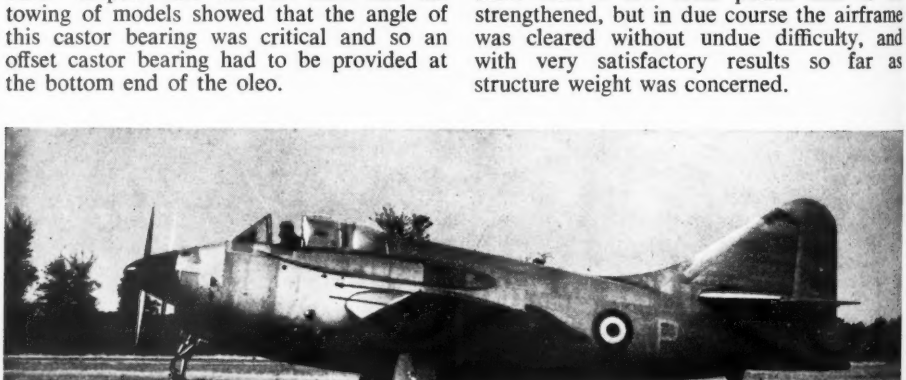

Fig. 14.
Gannet side view indicating catapulting attitude.

The author's opinion is that this is the most satisfactory method of obtaining a light and efficient structure.

The fly wheel effect of a turbine is considerable and after shutting the throttle there is an appreciable delay before the turbine loses speed. Again on the open up, as in a wave-off, it is found that delay in picking up speed is appreciable. Armstrong Siddeley Ltd. had made experiments with a single Mamba fitted with a Rotol propeller in a "Balliol" trainer using a constant speeding system, whereby the turbine was run continuously at constant speed and variations of thrust achieved by propeller pitch change. This system of control had been reported upon most favourably and therefore was introduced into the double Mamba power plant.

Under this system the turbines are run at constant speed with a slight penalty on consumption. To satisfy the constant speeding condition when throttling for landing, the flight fine pitch stops are withdrawn and the propeller blades are free to take up whatever fine pitch is necessary to satisfy the minimum shaft h.p. In other words, at the "cut," with turbines running at constant speed, the propeller approaches its ground fine pitch stop. It must be realised that to satisfy starting conditions, the turbine fine pitch setting is much nearer the discing condition than is the case with a piston engine.

The constant speeding system gives a satisfactory rate of loss of thrust at the "cut" and at gliding speeds enters a condition of negative thrust which provides a useful increment of drag.

Attention has been drawn to some features of interest in the development of the Naval type which is centred around the double engine. It is most satisfactory at long last, to see an idea for which the author's firm has striven for so many years brought to fulfilment by the joint effort of engine, propeller and aircraft design and development teams.

FURTHER DEVELOPMENT OF THE ANTI-SUBMARINE TYPE

For obvious reasons, care has been taken in the paper not to refer to developments of search and strike equipment.

Those who have been studying the problem of anti-submarine warfare realise that for this class of operation the fixed-wing aircraft, in due course, may give way to the helicopter. A large load-carrying, all-weather helicopter can solve a number of problems in a much simpler fashion than is possible with a fixed-wing aircraft. It will not only simplify equipment, but it should be possible for it to operate from the merchant ship, thus removing the necessity for the escort carrier, which itself forms an important and valuable target.

SUMMARY

Some of the problems which confront the designer of Naval aircraft have been described. From the three groups of Naval operational aircraft, the Anti-Submarine type was chosen for discussion, as it has provided a fund of fresh experience. Keeping the sea lanes open in time of trouble is vital for national survival, and it was judged that the subject would be of general interest.

The development of the Fighter and Strike Groups covers a wide and important field and might well form the subject of another paper.

The author wishes to thank the Fairey Aviation Company for allowing him to give this paper and the members of the staff that have helped him to prepare it. Valuable criticisms and suggestions have been given by members of the Admiralty and the Ministry of Supply. The opinions expressed are the author's and do not necessarily represent the considered views of his Company.

DISCUSSION

Rear-Admiral Abel-Smith, C.V.O. (Vice-Controller (Air), Admiralty): Among the many roles which the Navy was called upon to carry out in war there was certainly none more important than the anti-submarine role. Maintenance of the sea communications was their first task. They all knew well that in two wars the use of the submarine had very nearly been their end. Therefore there could be no better consideration for the moment than the effective use of aircraft against submarines.

It always surprised him that many of his submarine friends should tell him that it was little realised how big a contribution the mere presence of an aircraft could make towards

putting a submarine captain off his form. As soon as he saw an aircraft he had to assume that he too had been seen and might expect that in due course all the horrors of frigates, destroyers, etc., would be there to pour on him all the devices which restricted his performance and the likelihood of his getting a kill.

He remembered on one occasion when captain of an escort carrier near Greenland, in bad weather, they were working in the well known gap where shore-based aircraft could not reach (that would not occur again because aircraft had a longer range; a carrier could produce a variety and number of aircraft at the place required). They were working in that gap and they flew off one Swordfish with only two depth charges. After some time she reported a submarine and attacked it. Only one depth charge went off, but by remaining over the submarine and using her radar the aircraft had been able to direct a destroyer to it and the submarine was sunk in ten minutes.

In the course of interrogation of prisoners afterwards the captain of the submarine said he had not at first noticed the aircraft's approach, and when he did he dived in such a hurry that the crew failed to close one vent with the result that the battery was flooded and in order to avoid being gassed he drove the submarine to the surface by using his diesels, where he was duly despatched by the destroyer.

That story might sound a fairly simple matter, which it was, but to get the aircraft off the carrier on that job and take it on again, behind all that, lay a good deal of work.

Ships and aircraft had been mentioned as though they were complementary, but radical changes had to be made in the ship and in the aircraft before they could work together. Great progress had been made in the years since flying-on was started. He remembered in the old days in the First World War, although he was not himself flying then, when the first aircraft landed-on by means of side-slipping and being held down on arrival by the pilot's friends. Later there were catches fitted on deck, then various ropes like gymnasium climbing ropes, and sand bags with ropes on the same lines as the present arrester gear. Later still, when he came into it, they landed-on using fore and aft wires. Later still they produced arrester gear as it was now known and they saw landings at even higher speeds, but the aircraft designer nearly always overtook them and produced aircraft of greater speed than the poor naval constructor could provide ships to handle. It was a difficult problem, for equipment improved and got larger and so presented further problems to the aircraft designer.

The nose wheel undercarriage had been mentioned and he regarded it, together with the improved view as one of the major advances they had had in landing on the carrier. Did Mr. Hollis Williams anticipate that there would be any trouble in increasing the strength of the undercarriage to stand up to the additional strain it might receive owing to the different form of approach which was likely to be adopted with the nose wheel undercarriage?

S. Scott Hall (D.G.T.D. (Air), Ministry of Supply, *Fellow*): One of the principal themes of the lecture was the question of compromise, but Mr. Hollis Williams had stated that the particular type of Fairey 17 was remarkable for the small degree of compromise. That had astonished him because he would have thought of all modern aircraft the naval aircraft essentially attempted the maximum degree of compromise.

Reading the paper, he began to get slightly worried because the author had made a remark to the effect that the one compromise was the position of the radar set. He would have thought that that radar set was perhaps the most important thing in the whole aeroplane because that radar set had to find the submarine, which in the future would be using a snorkel and would be one of the most difficult things to search for from the air. Therefore he was raising a question which it seemed to him was not a small degree of compromise.

Mr. Hollis Williams had shown what another solution, that of having the twin-engine arrangement, with the engines outboard had led to, and he left it at that, except to stress the point which he was continually stressing, that they were moving into an era when the electrical equipment was, perhaps, the most important thing in the aeroplane, and it seemed to him that it should have the most careful consideration in the layout of any aircraft, for naval or land purposes.

Mr. Hollis Williams had also said that care had been taken not to refer to storage

and striking equipment, thereby observing the present secrecy and security regulations. He was beginning to feel that those regulations were very restrictive on their discussions. Could not they be lifted in order to enable free discussion of the impact of storage and striking equipment on the design of aircraft?

His next point was the quantity of armament. Those aircraft must drop something —he thought he did not infringe any security regulations there. It was a subject which was of supreme importance in aircraft of that kind and he would have thought some discussion of it would have been valuable.

There was navigation and navigational equipment. Could Mr. Hollis Williams see anything in the problem for compromise in the design of his aircraft?

He felt that the lecturer had been a little hard on the nose wheel arrangement and he had not understood the remark that the nose wheel aircraft tended to be landed-on more heavily.

Perhaps they had not thought enough in terms of specific engines and power plant for naval use. It seemed to him that the aircraft should burn the same fuel that the ships carried—they should use diesel oil and nothing of a lighter character.

Reliability and ease of maintenance were of supreme importance to the Navy, operating as they did, with very small spaces in which to do their repair work.

He thought that the great problem in the future would be the difficulty of reconciling the ever-increasing top speeds which were called for, with good landing characteristics. It seemed to him that they had reached the limit of present methods of reducing lift-drag and lateral control which they required for those speeds, and that there was a clear case there for ingenious designs.

Admiral Abel-Smith had touched on the question of collaboration with ship designers. That, he thought, was the most important aspect of modern naval aircraft design and it was one which was of peculiar difficulty because of its nature. There was the difference in scale or period of the expected air life of aircraft and ships. The ship lived about 25 years and it seemed to him that tremendous imagination was needed on the part of naval architects to produce a job which would be suitable for the aircraft developed over that time.

Perhaps the Ministry of Supply should take over the responsibility for the design of aircraft carriers as well as for the aircraft!

Captain Smeeton, R.N. (Director of Air Warfare, Admiralty): Mr. Scott Hall had already protested about security regulations; as far as security permitted he wanted to give them a glimpse into the future to see what the problems were, together with one or two ideas of possible methods of improvement.

Mr. Hollis Williams had said that design limits were imposed by take-off and landing and the handling of aircraft in confined spaces.

There seemed to be two avenues of approach to the problem of take-off and landing. The first, to which Mr. Scott Hall had already referred, was primarily one of the ship design and that was closely allied with the aircraft designers' work. Indeed, he would suggest that in a carrier, by its nature a large ship which had to steam at high speeds, they had a very large reserve of power available and it should be possible in some way to harness that power which was built into the ship to assist them in the problem of launching the aircraft, and secondly, could not they use it in some way to assist landing?

As regards take-off it might be possible to use the ship's power in some way to increase the end speed imparted by the catapult. In the case of landing they had probably seen photographs in the newspapers of flexible deck landings carried out in H.M.S. *Warrior* some two years ago. That was a clear case of using the facilities of the ship to simplify the problem of landing by transferring the energy absorption from the aircraft to the ship, thus enabling the designer of the aircraft to improve his design. Personally he believed that much could be done on those lines.

The second avenue of approach to the problem of take-off and landing was to arrange designs so that they contained landing and launching speeds of future aircraft within reasonably low limits. Here, he suggested, there was ample scope for the most ingenious mind. There seemed to be very little knowledge of the problems associated with some form of variable geometry of the aircraft in flight, and there was also a need for some method of devoting a greater proportion of available thrust to increase the

lift component when the aircraft was in the launching and landing condition.

In the handling problem Mr. Hollis Williams had said that the length of an aircraft was dictated by the length of the ship's lift. That was certainly true in the present conception of naval aircraft, but there were other considerations. With the advent of radar which could be carried easily in the nose of an aircraft of twin-engined design, they should investigate the problem associated with a detachable or folding nose, and the nose should be designed around the particular radar set which had been chosen for use.

It might eventually be possible to do away with the folding wing on small aircraft. As sweepback was increased the span tended to be reduced and it might be possible to store the aircraft in a canted manner in the hangar in such a way that the wing of one would overlap the fixed wing of the next, and so on.

He was convinced that as the weight of aircraft increased and the mass density or specific gravity were increased as well, there was a great future for mechanical handling. In that field he believed they should use the power which was built into the ship and was available to be drawn off in some way yet to be determined.

Mr. Hollis Williams had said the chief and foremost requirement of a naval aircraft was that the pilot should have an adequate view. He believed that with the new types coming into service the increased view would off-set the disadvantage of high approach speed and that they could expect a marked decrease in the deck landing accident rate. While they had achieved that advantage, he thought it was more than ever important that they should bend all their energies to reducing launching and landing speeds. This was not purely a naval problem. Some concern must be felt by the land-based air forces at the vast expenditure, in time and labour, required to provide runways for modern aircraft, and they might wonder how a tactical air force would keep up with an advancing army.

Would Mr. Hollis Williams say a few words on reducing landing speeds and take-off speeds by some of the methods that he had suggested?

G. E. Petty (Blackburn and General Aircraft Ltd., *Fellow*): He would like to say how courageous he thought the Fairey Company had been in pinning their faith to an undeveloped engine. His firm had had quite a lot of bitter experience in fitting undeveloped engines in prototypes and sometimes in production aircraft. To have the courage to go to a new type of turbine engine in a new prototype showed a lot of faith.

He did not propose to be historical, but he did propose to say a few words about the Blackburn G.R. When the specification was issued, they were "flirting" with the Napier Company, and in the Napier Double Naiad engine they thought they had the ideal answer to their problems. It was an engine of some 40 per cent. more power, which, on account of the increased thrust-weight ratio, enabled rather smaller wings to be fitted with a single fold, and some 400 lb. saving in structure weight. This was extremely important as weight was of primary importance since it was unknown what was the maximum weight which could be handled satisfactorily on deck. Another advantage of that engine was that it was a truly contra-rotating engine and, when flying on one engine, there was no change of directional trim, and so on.

In this connection, with the co-axial engine, he would like to ask—when flying on one engine with the other engine feathered—was there a rather unpleasant slow speed high amplitude oscillation over the tail, due to the effect of the feathered airscrew not being stationary except at one particular speed? They had found this a considerable disadvantage which would not have occurred with the Naiad. The Double Naiad engine had an advantage that the gear box was on the same level as the turbines and it enabled them to put the pilot considerably farther back, with greater accessibility to the engine, and still obtain a very good view over the nose.

Mr. Hollis Williams had mentioned the nose wheel undercarriage as an advantage, and he was glad to see that a number of following speakers had stressed the extreme importance of this type of undercarriage to naval aircraft. He thought it was the absolute answer for naval pilots, because not only had they to get into a small space, but they had to take into account the pitching and rolling of the ship. To feel that they could put the aircraft down and it would sit on the deck without float, must be a very reassuring feeling.

High lift devices had not been mentioned, he presumed for security and censorship reasons. But it was always a bugbear of the naval designer. He was convinced that they were getting to the end of high lift devices of conventional form, as the lecturer had remarked, but if, on the other hand, they were to go to other devices of boundary layer control, and so forth, they would face an additional complication of variable incidence wings, and if it should be necessary to put a variable incidence wing on, say, a double folding wing, and perhaps a kneeling nose wheel undercarriage, they would be getting even more complicated.

What did Mr. Hollis Williams consider was the maximum usable C_L that they could get with naval aircraft without causing undue induced drag? They found they were nearly there now and would have to get other means of increasing lift.

There was one point he would like to raise, in view of the various remarks made on "compromise": The work of any designer, and he thought it applied particularly to the naval designer, would be considerably eased if they could get a specification and stick to it. One got a little tired of finding, when half way through a job, that it had to take three instead of two persons, and so on. In the end it tended to be a compromise from the nose to the tail.

D. Keith-Lucas (Chief Designer, Short Brothers and Harland Ltd., *Fellow*): He agreed with Mr. Hollis Williams on quite a number of points, but strongly disagreed with him on the position of radar scanners. There was one piece of apparatus which, he thought, was perhaps even more important than the radar scanner and that was the very delicate and sensitive piece of spotting equipment, the human eye. They had talked a lot about view, but only in connection with deck landing. There was also the very important matter of view while spotting.

It was his contention that not only should the pilot have a good view, but the observer also, and both should have the same view as nearly as possible. It was often difficult to get even a man sitting beside one to see what one easily saw, but it was much harder if he were not sitting beside one.

The question of view was introducing one or two new problems. When they got something approaching perfect view—the Vampire was a case in point where the pilot was well forward with nothing in front of him—the pilot began to lack the reference of the nose stretching out in front of him, which gave him some indication as to his attitude as he made his approach to land. Without that he thought they had to give the pilot something else, preferably an air speed indicator which was not only placed near his line of vision, but which was also focused at infinity. It had to be a reflecting A.S.I. on the same lines as a reflecting gun-sight so that the pilot saw the speed written, as it were, across the chest of the batsman.

He also disagreed with Mr. Hollis Williams on his interpretation of the landing problem. He felt that they had to give the pilot a much wider tolerance in speed. Their aim surely should be to make it so easy for the pilot that if he got his aircraft on the deck in the right place it would stay there. Obviously that was beyond their reach at the moment, but at least they could give him tolerance in speed which did not, in his mind, line up with Mr. Hollis Williams' idea of the nose wheel coming into contact so early. Early contact of the nose wheel meant that if they came in too fast, or on a deck which was pitching bows up, the nose wheel would hit first and cause a bounce. He was not working on behalf of mollycoddling pilots. On the contrary it seemed to him that what they had to do was to make it possible for the pilots to fly their aircraft in any weather in which submarines could operate. Let them compromise a bit on the problem of take-off in favour of making landing as easy as they possibly could.

Lt.-Cmdr. Reynolds: He thought that attitude in deck landing was something that a pilot sensed and for which he needed no indication continuously of his attitude. If he approached at the right speed he could virtually feel it by the feeling in his bones. On one machine the pilot had been given an indicator to give him an indication of attitude, but he thought the average pilot in deck landing ignored it. He could sense his attitude and the speed to the deck.

He thought that with the tricycle undercarriage the pilot could come in without any trouble at all up to 1.3 Vs. If there were any trouble he could put the aeroplane on deck and get away with it.

They had talked a lot about the double-engined Mamba and its reliability. It did give single-engined reliability with an ease

of handling. The Americans had developed the combined engine to a high state and he would like an opinion as to whether the prop-jet was a good proposition compared with the thoroughly developed combined engines that the Americans had developed—a big rotary with turbo-driven superchargers?

L. W. Rosenthal (Saunders-Roe Ltd., *Assoc. Fellow*): They had heard a number of comments on the relative priorities to be given to the human eye and the radar equipment during the design of a naval aircraft. He might be misinformed but he had been under the impression that radar equipment was introduced because the human eye could not cope with the problems which had to be solved, *e.g.* could not see far enough during the day and its vision was inadequate at night. He would have thought that with this in mind the radar might have had some priority over the human eye.

It was interesting to note that a considerable effort had been made to land aircraft without the pilot requiring to see at all, and although this problem had not been solved sufficiently to enable the equipment to be used under operational and normal circumstances, surely there would come a time when the equipment had been perfected so that the question of view for the pilot would cease to have any importance.

In view of the earlier discussion, this particular point might well have a considerable bearing on the design of future types.

Another point which proved rather surprising was the fact that in the discussion on naval aircraft which was held four years ago, it was suggested that the naval aeroplane might eventually need no undercarriage. Presumably the background for this statement was the flexible deck.

This very important feature had only been mentioned once during this particular discussion. Surely the aircraft designers would be expected to be particularly enthusiastic about building an aircraft which need not be fitted with a heavy and difficult component like the undercarriage, and in view of this he would like to hear what Mr. Hollis Williams had to say about the influence of the flexible deck on the design of future types.

MR. HOLLIS WILLIAMS' REPLY

Rear-Admiral Abel-Smith: In answer to the question about the additional strength that would probably be required from the method of operating nose wheel aircraft, he thought that firm contact with the deck could be obtained after a high rate of sink, given proper length of oleo stroke with good recoil damping. The penalty of dealing with high rates of sink was a proportionate increase of undercarriage weight. The normal method of design was to absorb the landing impact and the two main wheels; the aircraft then gathered angular momentum as it pitched forward on to the nose wheel which, in turn, loaded up the nose wheel structure.

As mentioned in the Lecture, it was a helpful feature to arrange if possible for the nose wheel to come into contact early, which prevented the build up of angular momentum and helped to distribute the landing load among all three wheels.

Mr. Scott Hall: In connection with the first question, concerning compromise, with special reference to the positioning of radar equipment, he agreed that the remarks in his draft written paper might have given an incorrect impression.

On re-reading this section of his paper, he had realised that the impression was conveyed that an important and expensive piece of apparatus was being carried in a position where it could not be used effectively. In his spoken Lecture he had qualified this by saying that whereas the positioning of this equipment was restricted in an aircraft with a nose power plant/propeller combination, it could be made to operate effectively with correct overall design of aircraft attitude under "search" flight conditions.

The nose installation in a conventional twin-engined aircraft would give a completely unrestricted forward scan, whereas the underslung installation with a central power plant might give slight shadowing of the scanner picture presentation.

With reference to Mr. Scott-Hall's second question, he fully agreed that some slight relaxation of "security regulations" at an earlier stage in the life of an aircraft would enable a great deal more information of value to members of the Society to be imparted and discussed. At present, the aircraft mentioned in his Lecture had reached part publication status only, which restricted the discussion to those features which could be observed by external examination only.

Navigational equipment had been in a state of rapid change and development, but by designers and service operators working

together, a satisfactory arrangement had been achieved.

The tail wheel aircraft demanded deck landing approach conditions which had to be held within fairly narrow limits as regards speed, attitude, and rate of sink, to avoid bounce.

The penalty from bounce was the likelihood of floating over the wires into the crash barrier and therefore the pilot had to exercise great skill and judgment.

With nose wheel aircraft, a much wider tolerance on approach conditions could be accepted, and provided that recoil damping was adequate, there was little likelihood of the hook missing the wires. He judged, therefore, that it would be found possible to operate such aircraft under much rougher conditions and therefore the percentage of heavier landings would increase.

He anticipated that the turbine engine would make a great contribution to reliability and ease of maintenance. Turbines had already given a very good account of themselves in comparison with reciprocating engines. They were still in an early stage in their development and the outlook for the future was hopeful. Ease of maintenance was receiving more and more attention during the design stages and although aircraft tended towards increasing complication, a great deal of attention was now given to ready access and replacement of components which might be expected to need attention.

Captain Smeeton: With regard to the general problem of reducing speed for take-off and landing, the main line of development at present was to improve wing flap systems with the object of achieving an improved coefficient for $C_{L\,max}$ without an associated increase of C_D. In such flap systems, the moment coefficient also tended to be high, which introduced tail control problems, especially on naval aircraft, with dimensional limitations. This was particularly apparent in the landing condition, especially when associated with a constant speed propeller-turbine. At the "cut," the propeller moved to a fine pitch condition of the blades to satisfy the constant speeding requirement and this introduced a large increment of drag, which was additive to the aircraft drag and also promoted a loss of slipstream velocity.

The problem of developing tail controls to be sufficiently effective under those conditions was becoming increasingly difficult and indicated that a temporary design limitation was being approached.

He thought that the next big step forward would come from some form of boundary layer control, which was giving promising results under laboratory conditions.

Mr. Petty: He remembered that the point about propeller effects on the co-axial double engine with one engine put down and feathered had been mentioned in the pilot's reports. The problem was to bring the feathered propeller completely to rest when it was working either in front of, or behind, the other propeller. At a certain point in the slow rotation of the feathered propeller, a measurable bump had been recorded.

No development time had been spent on the elimination of this feature because it was barely noticeable and in any case, a brake would be available. Brakes were necessary to bring the propeller to rest when striking down the aircraft and the same brake could be used under airborne conditions to hold the feathered propeller stationary.

He had emphasised the value of obtaining lift without drag and, incidentally, without too much moment.

The problem of tail control with the propeller-turbine engine was becoming acute with a high lift coefficient of the order of $2\frac{1}{2}$ engine "on," forced by a backwards moving flap system.

He certainly agreed with Mr. Petty's remarks on the changing nature of specifications, but on the other hand, in these days of rapid improvements, equipment and methods of operation, failure to keep pace with such changing viewpoints would merely increase the rate of obsolescence of the type. He thought it was essential that Air Staff should have a continually changing outlook to take account of new methods and new equipment and it was up to firms to try to keep abreast of such changes.

Mr. Keith-Lucas: The positioning of scanners and search view for pilot and observer all came back to the point he had made at the beginning about the importance of the designer making up his mind as to the order of priorities for the various requirements. Mr. Keith-Lucas obviously assessed those that he had enumerated as the most important and that had led to a particular type of aircraft. Other designers might have different ideas as to the priority in which

operational requirements should be assessed and that led to alternative designs of aircraft.

Thus, everything came back to the importance of the initial design decisions.

Mr. Keith-Lucas's suggestion about a reflecting A.S.I. struck him as particularly valuable and might well be followed up.

He had not intended to give the impression in connection with remarks on the value of three-point contact with nose wheel undercarriages, that it required a critical speed to accomplish this effect. The value of the nose wheel coming into contact early could be exploited over a moderate contact speed range, say 10 knots, but if excessive contact speeds were attempted, then it was a condition which might lead to bounce.

Lt.-Cmdr. Reynolds: The question about the merits of the combined engine was mentioned in the written paper, but was one of the sections which he had omitted in the lecture to save time.

A summary of this section was that up to 3½ hours endurance, the weight of the double engine plus its fuel, had the advantage. Between 4 and 6 hours endurance, the piston engine plus its fuel, probably gave the lightest weight, and about 6 hours, it paid to compound the piston engine.

Mr. Rosenthal: He agreed with the remarks on radar. It could see under conditions which were blind to the human eye. On the other hand, there were many occasions under which the reaction of the human eye was quicker. Radar was the answer to conditions of bad visibility.

With regard to the question about the design of aircraft without undercarriages, he had been tempted to try to cover the whole question of naval aircraft, but it was obviously too vast to deal with in the time and so he had concentrated on the anti-submarine type.

Mr. Rosenthal's question would be applicable mainly to fighter types. In the case of the anti-submarine type, there was a free take-off requirement in a short distance, which meant propeller or a propelled engine, and therefore in this case, there was no question of a flexible deck landing.

AIR TRAVEL
From the Passenger's Point of View
A DISCUSSION

A Discussion on "Air Travel from the Passenger's Point of View" was held by the Royal Aeronautical Society on the 26th April 1951 at the Institution of Civil Engineers, Great George Street, London, S.W.1. Major G. P. Bulman, C.B.E., F.R.Ae.S., President of the Society, presided at the meeting.

The discussion was opened by Mr. J. F. S. Huntington, a King's Messenger, and Lady Douglas of Kirtleside.

The President: The subject for discussion was a little unusual for the Society. Usually they considered the technical and scientific aspects of aviation—the production of aircraft, their equipment, and so on—and did not often consider principally the people who used them. It was felt, therefore, that at the concluding meeting of the 1950-51 Session they should obtain the views of people who had done a great deal of flying, and give an opportunity also to the airline operators, aircraft designers and others to join in the discussion.

They were fortunate in having two distinguished people to open the discussion.

Mr. Huntington had been flying as a King's Messenger for a considerable time; in fact, he had said that about 90 per cent. of his working life since 1947 had been spent in the air, flying to and from practically every major country in the world.

Previously he had served in the Palestine Police, from 1935 to 1938, and in tanks in the Army from 1939 until he was captured in North Africa in 1942. His first flight was made as a prisoner-of-war when he was transferred from North Africa to Italy. He was a prisoner-of-war from 1942 to 1945 in Italy and Germany. When released he went on a special mission to Japan to interrogate released prisoners-of-war.

In view of his wide experience of flying, he had great interest in the provision made for the comfort and safety of the passengers.

The second opening "bat" was Lady Douglas of Kirtleside, who was also very welcome as one who had done much flying, and it would be particularly interesting to hear her reactions, which he hoped, and expected, would be highly critical.

J. F. S. HUNTINGTON

He confessed to some degree of diffidence as he was not a fare-paying passenger, but his job was rather unusual and the number of hours he spent in the air was anything from 800 to 1,200 a year. He flew mostly on British airways, but he also travelled on American, Scandinavian and most of the other airlines that were in operation.

The first matter, from the point of view of the passenger, was that of handling on the ground. There was much variation in this, not only over the whole world, but even in London. Northolt was better than London Airport at Heath Row; it seemed to him also that there was much less staff there, not too many people walking around with rings on their arms.

King's Messengers were not dealt with in quite the same way at airports as were ordinary passengers; although they had to go through the same routine, they did not always follow through with the other passengers but were conducted separately. At Northolt, so far as he could see, the normal passenger was served better than at Heath Row. At times he had had to wait for three quarters of an hour to get a porter; that was not the fault of the operators, but of the traffic staff—they had forgotten.

At airports overseas, B.O.A.C., for example, would have probably a manager and one other Britisher, and in addition a number of local people, and the efficiency of handling dropped considerably, but that was not the fault of B.O.A.C.

Seating in aircraft was most important. When travelling long distances, such as to Tokio and Singapore, he had found the seats to be extremely tiring. They could lean back to a certain extent, but not a lot, there was very little leg room, and if one fell asleep one's head seemed to fall off, particularly if one occupied the seat next to the gangway. In his view as a passenger, seating was one of the most important features in aircraft and should be made comfortable, with sufficient leg room. When flying to Tokio the first night stop was at Hong Kong, and it meant flying throughout two nights; it was important, therefore, to have a seat wherein they could recline and stretch their legs straight out, the seat being adjustable to a reasonable inclination.

Inside the aircraft the pressurisation was good, but the humidity was such that the mouth and skin became dry. He did not think he had ever travelled in an "Argonaut," for example, in which the humidifier seemed to be working properly; there seemed to be no moisture at all in the air.

Another irritating item, which it might not be possible to change, was the amount of filling in of forms which had to be done. At each stop they were given a whole sheaf of forms and, having filled them up, when they arrived at the destination there was nobody who seemed to want to take them and use them. It seemed to him to involve a great waste of paper.

In 1950 he was based for six months in Washington and had flown from time to time between Washington and Mexico, with a touch-down at Dallas for re-fuelling. He had found the American airlines excellent in every way. The handling was good, the aircraft were comfortable; the seats would recline and the occupants could stretch their legs. His flights were always made at night, leaving at 11.30 p.m., and one pleasant feature was that the lights in the aircraft were dimmed. On other airlines he had noticed that after the take-off the lights were put out if the passengers wished to sleep; but about ten minutes before landing they were awakened by a glare of lights. That was not good from the passengers' point of view; usually their hair was all over the place, and the women's make-up might have slipped a bit. The dimmed lighting on American aircraft was rather pleasant and when a passenger awakened, the attendant would switch on the individual light.

Although he had said that the handling of passengers by the American airlines was good, he had had one experience which had proved the exception. On one occasion he was conducted to an aircraft which he had thought was flying to Dallas and Mexico. After flying for some time, a message came through from the cockpit, "This is the captain speaking; we are now about to land at New York." It was not pleasing to find that he had been flying in the wrong direction. But that was the only occasion on which the American airlines had put him on the wrong aeroplane.

He had had some experience of flying in Russian civilian aircraft. The actual flying was good; the pilots were excellent and the crews seemed to be efficient. When he had first flown on the Russian aircraft they had flown at about 500 ft., which was bumpy, but in time the height was increased to about 5,000 or 6,000 ft. An aircraft was liable to take off with a petrol tin rolling up and down the machine. When a man was filling the tanks with petrol he was liable to smoke a cigarette, and there was no such thing as a fire extinguisher available when the engines were started. At one time they did not even run up the engines, although they did nowadays. They had used the 1012 type aircraft operating on the particular route he had to travel, between Berlin and Moscow. It was comfortable, although slow, and it was fitted with oxygen supplies. He did not know the height to which it could go, but obviously it could achieve a fairly reasonable height.

LADY DOUGLAS

She had started flying just before the 1939-45 War; she had flown once for five minutes, but was ill and frightened, and had hated it. The next occasion was when her husband was British Commander-in-Chief in Germany, in 1946. There it was part of her job to fly everywhere in all conditions, and since then she had travelled many thousands of miles by air on civil airlines all over the world, realising now that it was the quickest and most comfortable means of transport and, from a woman's point of view, much the cleanest.

The really well-run airline "sold" the aeroplane. In other words, the average passenger did not think much about the technical side, or the advantages of the latest type of aircraft. What appealed to passen-

gers was the internal service on the aeroplane, the comfort, the seating, and so forth, and she could not stress too strongly how much the attentions of the steward or stewardess were valued; they could make or mar a trip.

It had now been decided that pressurisation was essential on all future air liners. It would mean that they could fly above the bad weather and thus avoid air sickness and all the horrors of a bumpy trip. She recalled a personal experience of a very unpleasant flight between Athens and Rome, when, owing to lack of pressurisation, the aircraft was unable to fly sufficiently high to dodge the storm and the attendant unpleasantness. Most of the passengers were very air sick.

A personal point which all passengers appreciated was the visit of the captain during the flight. It gave them a feeling of confidence and well being, and added greatly to the pleasures of the trip for him to explain the route and the points of interest. It might well be in the future, when air liners were so vast that they would each carry a hundred or more passengers, that that personal attention would have to be discontinued, and they would have to adopt the American system by which the captain talked to the passengers by loud speaker. But the individual touch meant much to passengers, and she hoped it would always be possible to keep that custom.

A matter which it must be difficult for the crew to decide was what to tell the passengers in the event of something going wrong. In her opinion passengers should be told the truth so far as possible. Most people could take it, and the trust and belief in the crew was complete and absolute. Sometimes, perhaps, they did not show that enough.

Her personal view was that the comforts of air transport depended greatly on the following factors:—

(*a*) The seating,

(*b*) the position of the windows,

(*c*) the service given to passengers,

(*d*) the food, and

(*e*) the personal touches to the interior of the aeroplane.

It was essential that the aircraft should not be over-crowded; that the passengers had enough elbow and leg room and that all seats were adjustable to each person's convenience. The question of tables was debatable; most women preferred to have them — they provided a place on which to put a handbag, and made eating and drinking more comfortable.

Surely it would be possible to have larger windows in the new types of aircraft, so that the passengers could have the best view possible? There was so much to see in the way of cloud effects, sunsets, sunrises, all the flood of colour over sea and mountains, as well as the interest of coming into a strange country when approaching to land, or taking off from a great city which had been visited and which could be seen all over again from a new perspective.

There was great controversy as to whether passengers preferred a steward or a stewardess. She felt that the question of sex came into that problem; in other words, a man preferred a good-looking stewardess, while a woman was equally happy to be looked after by an attentive steward. She was not going to get herself into trouble by saying which she considered to be the better; the ideal was to have one of each.

Food was a subject which aroused much public feeling. The British airlines were handicapped by two things; one was rationing, and the second was the high cost of unrationed food. It would be agreed by most people that it would be wrong to increase rationed food for air passengers and not for the ordinary British housewife and the people generally. The serving of hot drinks—tea and coffee—was always appreciated; and as at present it was possible to serve only cold meals on British European Airways, those should always be accompanied by a cup of hot soup. She understood that as soon as the new types of aeroplane were in use they would be equipped with facilities for serving hot food, which would make all the difference. Flying was apt to make people tired; the change of altitude affected some people's vitality and there were those who suffered from a certain nervous tension, especially if they had not flown much before. The stimulant of hot food would do much to counteract that.

Coming to the personal touches to the interior of the air liners, she would like to see a mirror in the back of every seat, so that passengers could have a chance to tidy themselves peacefully, instead of joining the long queue to the cloakroom, where the one and only mirror was situated—usually in the wrong position! Would it not be possible to have a thin sheet of aluminium with a polished chromium finish attached to the

back of each seat, complete with a small packet of face tissues, all very useful if anyone were ill? Women would also like some make-up in the cloakrooms—it was already provided on the long-distance aeroplanes—a little powder and some toilet water could make a lot of difference to morale.

As a passenger she paid tribute to the Aircraft Industry, to all the hundreds of people, so many unknown, who had done so much for the comfort of passengers. Few of them thought about that. It was very easy to step into a luxury air liner without giving a second thought as to how it came to be constructed, or how much work, energy and human endurance went into its making in order that the passengers should be comfortable and, above all, safe. But one thought a great deal about flying when one had done so much of it, and tried to understand and follow the progress it was making all the time.

She wondered how many passengers ever thought of the lives that were lost in the cause of aviation—the test pilots who gave so much for what seemed to be so little recognition. Few ever knew them, or heard of them until perhaps an unhappy headline appeared in the newspapers. When she returned from a long, sometimes rough and perhaps unpleasant trip, she felt that they should all think more of those men who had made flying the wonderful thing it was today.

GENERAL DISCUSSION

G. R. Edwards (Chief Designer, Vickers-Armstrongs Ltd., *Fellow*): He fully agreed with Mr. Huntington that the seating was important from the passengers' point of view; he did not suppose there was any other part of an aeroplane on which so much time was spent in doing things the wrong way. Great effort and many man-hours were expended on thousands of tests, and so on, with a view to producing a good seat; and he had a suspicion that the "Argonaut" seat, about which Mr. Huntington seemed to be so critical, had emerged from his own organisation, even if that particular aeroplane did not come from that source. He could only quote in defence of that seat the number of people, many of high rank, who had sat in it. It was one thing to say that a seat was not very good, and it was another thing to be able to say how to make it right.

If Lady Douglas wanted a mirror at the back of each seat it would be simple to provide it; but the weights of all those little mirrors would mean that the pay-load carried by the aeroplane would be a little less, so that fares would probably go up. Was Lady Douglas prepared to pay the extra fare for having the mirrors?

Designers were a simple type, but they found it difficult to determine what it was that the passenger wanted most. To travel a little cheaper, or in greater comfort, or with greater safety?

He had always felt, in respect of comfort, that the answer was conditioned by the circumstances in which a passenger was travelling. If, for example, he travelled on a large expense allowance from his company, everyone would know that he had never been known to travel anywhere at any time except in the absolute height of luxury and comfort. But the passenger who paid his own fare, and maybe could only just afford to travel by air, might vote for the seats being closer together, for a little more austerity, so that he could travel perhaps a little more cheaply.

How much were passengers prepared to pay for safety, because, as in all other things, it was not achieved for nothing? If an aeroplane, equipped with 40 seats, were to crash, provided that the seats were strong enough to cope with a 15*g* backward acceleration, and provided that the seats were attached to the floor of the aeroplane in such a way as would enable them to receive that acceleration, there seemed little doubt that the people would remain reasonably intact, or that they might suffer just a few broken legs and things, if there were no fire. But to make that provision would mean probably taking 700 lb. off the pay-load of the average 40-seater aeroplane today, and up would go the fares again.

He did not believe there was a simple solution to the problem; it was a problem which those who made the aeroplanes found it a little difficult to resolve on their own.

Again, he had no doubt that the mirror was in the wrong place in the ladies' room. Mirrors always were in the wrong place. But he could assure Lady Douglas from his experience that not only would all the brains among the aircraft constructors concerned have been brought to bear on the problem of placing the mirror, but that the customers also would have sent legions of technicians to ensure that the mirrors were in the right places. He felt that they tended to get rather distorted ideas on that sort of thing; and the

answer was that they could not make everybody happy.

Having spent a fair amount of time flying in America on the various types of aircraft in use, he confessed that he began to feel that there was much to be said for the safety aspect. Perhaps one who was engaged in his job would take a rather distorted view of things. He had flown in one aeroplane—which had made headlines when its wings had come off in rather precipitous fashion—and for $1\frac{3}{4}$ hours, flying over rough-looking mountains, he had suffered anguish in watching the wings bounce up and down. That experience had made him aware that he was at the passenger's receiving end at that time, instead of the giving end.

He had felt that in the American aeroplanes in which he had flown there were many things which were worse than things in the average modern British aeroplane. For example, he did not think the standard of comfort in American aeroplanes compared with the modern standard in British aircraft. The majority of travelling on American airlines was domestic travel, so that the operators had not to worry about frontiers, and ground handling therefore became easier.

He expressed gratitude to Lady Douglas for her kind reference to the efforts of the Aircraft Industry as a whole, and particularly to the work of the test pilots.

Lord Douglas of Kirtleside (Chairman, British European Airways, *Hon. Companion*): It seemed to him, with regard to the seats, the positioning of mirrors and other small things which made so much difference to the passengers, that the Aircraft Industry made very heavy weather over what should be a relatively simple job. Mr. Edwards had designed some wonderful aeroplanes; but when he was asked to design a seat, which ought to be fairly simple, he seemed to find it extremely difficult, and he could never understand why. B.E.A. had considered and tested many new types of seats, some made by Vickers and some by other firms, and it was curious that so many faults were found. He had what was no doubt an illusion that if he really got down to the problem, he could solve it on his head! Yet extremely clever people seemed to find it difficult.

Having done quite a lot of flying in America, he disagreed with both Mr. Huntington and Mr. Edwards with regard to certain aspects of the standard of passenger handling there; he had found that American handling on the ground, *i.e.* before the passengers got into the aeroplane, left much to be desired. Arriving at an airport with a mountain of luggage—and Lady Douglas always travelled with a mountain of luggage—probably ten minutes or a quarter of an hour would be spent in finding a porter. Passengers had then to find their way to the counter of the airline on which they were travelling, which took a bit of doing, and on arrival there sometimes 20 or 30 people would be found struggling to get their tickets stamped and to push their luggage through the hole in the counter so that it could be taken to the aeroplane. There was a not very comfortable lounge in which to sit and wait until an indecipherable voice was heard indicating at which gate they should report. Passengers then dashed wildly down the passage, and finally arrived panting at the particular gate, which was not always easy to find. He suggested that that did not compare favourably with the way in which passengers were treated by B.E.A. and B.O.A.C.

On the other hand, having boarded the aircraft, the conditions were extremely good. The American stewards and stewardesses were excellent, the food was good, the aircraft were very comfortable, and the standard of skill of the pilots and crew were very high.

He was a little surprised that Mr. Edwards had not mentioned the problem of noise, because his new passenger air liner was particularly good in that respect. It was important to reduce the noise level in the modern air liner to the lowest possible point, for noise was perhaps the most tiring factor of all! Constant beating of the air on the ears was more tiring than anything else. Perhaps others would care to express their views on that matter.

A. C. Campbell Orde (Deputy Operations Director, British Overseas Airways, *Assoc. Fellow*): The comments made so far from the point of view of the passengers were typically British. B.O.A.C., however, had inevitably to carry people of all nationalities, and one of the difficulties experienced was to obtain a true cross section of public opinion. It was also difficult to obtain a suitable measuring stick; it was difficult to make an effective passenger research.

The experience of B.O.A.C. was that an increasing number of children of all ages

were flying, and he considered that was rather a significant trend. When he heard references to the importance of reducing the noise level he wondered what would happen when they really got the noise level down very low and when there were a lot of children chattering. There was also the problem of keeping the children under control. There had been a number of complaints lately about children, and it seemed to him that before long they would have to have in the larger aircraft some means of isolating the children from the grown-ups.

To save dollars B.O.A.C. had obtained in Great Britain a seat similar to the one already designed for the Argonaut, which was bought in Canada. The pitch had to be short and the dimensions of the cabin were such that the room available for the seats was strictly limited; so that they could not accuse Vickers of being responsible for the experience which had led to Mr. Huntington's criticism. As to the future, they had now produced a seat based upon a design which B.O.A.C. had been developing for years and they had made a very good job of it indeed.

B.O.A.C. had been devoting a tremendous amount of research to the problem of rearward-facing seats for some time and were particularly interested to determine what they would have to spend in terms of increased weight in order to increase safety. The problem was not so simple as just the installation of rearward-facing seats.

S. Scott Hall (D.G.T.D. (Air) Ministry of Supply, *Fellow*): He was not a representative passenger, for he had been connected with the design of aircraft throughout the whole of his working life and he supposed he really knew too much about them.

It seemed to him that the three great factors to be considered were safety, comfort and economy; and he had engaged in many discussions on the question of how much they could afford in terms of added weight to ensure the first two requirements. He recalled a particular discussion some years ago on the amount of weight which could be afforded on de-icing equipment. Soon afterwards, when he was flying across the Allegheny mountains, in America, in totally blind conditions and heavy icing, he had wished the answer he had given in the earlier debate had been somewhat different; in his situation in the aircraft he had had no doubt which solution he would have favoured at that particular moment!

He felt strongly that mental comfort was by far the most important factor. It seemed to him that in the aircraft business they expended a tremendous amount of effort on physical comfort, and that if those concerned with other means of transport, such as trains and ships, spent half as much time on physical comfort they would achieve something really wonderful in travel. But he did not think too much effort could be expended on trying to achieve mental comfort in newer and less familiar forms of transport.

What were the factors leading to that? He felt that, until some of the more lurid accounts with which they were regaled concerning flying and best sellers based on them became a thing of the past, they would not achieve complete mental comfort in the passengers' minds. They had to feel sure that everything in an aeroplane was working. He had taken some pains to find out the reliability of equipment in ships, and had been somewhat surprised to find that on some of the most reputable shipping lines, many instruments went out of action from time to time. This did not really matter so much, because to a large extent ships could do without them, but that was not so in aircraft. They did not carry in an aeroplane anything that was not essential; yet if they had an opportunity to look around some aircraft in flight, how many things did they find unserviceable? It had been a shock to him on more than one occasion. He pleaded that the Aircraft Industry should give far more attention to reliability.

Again, a tremendous amount could be done by the crew. He had recently made a crossing of the Atlantic and had been greatly impressed by the confidence inspired by the crew of the aircraft in which he had travelled. He believed much of that confidence was due to the fact that the captain had a good idea of passenger psychology and was able to explain to the passengers just what was going on. That attitude was frequently lacking; passengers were bundled into the back of an aircraft, the door at the front slammed with a bang behind the crew, and until the aircraft landed at its destination they had no idea what was going on. That perhaps did not matter in a ship, because the progress from port to port was easily understandable; but it was rather confusing for air passengers nearing the end of their journey, when the

aircraft began to turn in a never-ending circle and they were left wondering why it was performing that orbital manoeuvre, not realising that they were either awaiting their turn to land, or that the aircraft was manoeuvring so that it could be identified for G.C.A. More might be done, therefore, to train crews in passenger psychology and in telling the passengers plainly what was going on. Nothing was worse than a bad psychological approach in that matter. As an example, on one occasion when travelling in another country, there had been a fatality due to bad visibility in the morning, and all the newspapers had carried lurid headlines about the accident. When his aircraft had started its journey and the passengers had the newspapers on their knees, the pilot had come into the cabin and had said: "The weather is very bad at the other end, there are icing conditions, the visibility is zero-zero, they have refused us at the regular airport and we are to land at a military airport. But don't worry; this is what we are used to." That was a bad psychological approach, he thought.

On long flights the question of the size of the aircraft was a major factor. It seemed to him that the benefit to passengers of being able to get out of their seats and to get into another "bit of scenery," however little removed from the seats in which they had been sitting, was of inestimable value. The value of diversion, of having something to do on the journey, was singularly important. In his view the real highlight would be travel in which they did not realise that they were travelling. That was why ships like the "Queen" vessels were like floating cities to many people. Drinking was a wonderful diversion; and the Stratocruiser, with very small additional space, allowed the passengers to indulge in that diversion to some extent. With the increasing size of aircraft they could obviously go much further than that limited change of occupation.

He supported the remarks made by Lady Douglas about the provision of windows, and urged that they could enjoy their journeys still more by trying to map-read during overland journeys. He thought that might be studied as a means of interesting passengers in what was going on.

He had strong views about airline food, and did not understand why it was considered necessary to serve things like steak for breakfast, as had occurred in his experience.

He also supported the comment of Lady Douglas about the value of good stewardesses.

P. G. Masefield (Chief Executive, British European Airways, *Fellow*): They had hoped to hear about the airlines from the passengers' point of view, but, apart from Lady Douglas and Mr. Huntington, they had not yet heard what might be termed a really "crude" passenger, that is, one who had not been "processed" by the Aircraft Industry He hoped some might appear.

On the other hand, there was quite a lot that could be said by the airlines about the passengers. But he supposed that they should take the view that "the customer is always right," especially the fare-paying passengers.

But there were difficulties about pursuing the policy of the passenger always being right. For example, he had received letters from two passengers on the same flight. One wrote that the conditions were far too austere and that more comfort was desirable. The other said that much too much luxury was offered considering that a loss was being made.

He felt that, to over-simplify the issue, the job of the airline operator was to offer improved communications. The objective should be to provide by air the best means of travelling from A to B from every point of view—including mental comfort as well as physical comfort. Safety was paramount. Regularity was perhaps the second requirement. Frequency of service was a third, because a fast aeroplane was of no value unless it operated often enough to offer a means of transport at the desired time. Next came cheapness, so that the man in the street could afford to fly. The final essential was for the airline to operate the service without losing money.

In achieving all those desirable features the operators had a real task before them. Comfort had to be judged very clearly against the length of flight. A flight lasting for one hour could be made in quite different circumstances from a flight lasting 12 hours such as across the Atlantic, or a flight of several days such as to Australia.

Aircraft size was important and, he thought, was becoming more so. As a believer in large aircraft he thought that the requirement was for the biggest aeroplane which could be filled at the necessary

frequency. Obviously that size was going up and up. One day the "Brabazon" would be the right size of aeroplane for the London-Paris service.

It was found increasingly, and sometimes deplored, that four-engined aircraft were a great selling point with some passengers. Certain airlines which had four-engined machines were liable to advertise that fact against those whose aircraft had twin engines.

Seating, including the provision of backward-facing seats, presented a big problem. He had an open mind on the subject and much research was going on. But he wondered how passengers would react to entering an aeroplane through a door at the back and seeing a sea of faces looking at them from backward-facing seats. The psychological aspect was important. One aspect which might react both ways was the knowledge of passengers that the seats were turned round in order to protect them in the event of a crash. It might make them feel that the aeroplane was not so safe as they had been led to expect. There was much to be said for and against backward-facing seats. One thing was quite clear—the thing to do was not to have accidents.

In regard to seat comfort, B.E.A. had a good test team made up of people with a wide range of anatomy, starting with the Chairman and himself, and going on down to the smallest office boy! If they could evolve a seat which would suit all those different forms they would be content. It was not easy.

The problem of the size of windows was also difficult. He did not believe the Aircraft Industry—with the possible exception of George Edwards, who had provided a magnificent size of window in the "Viscount"—had appreciated the importance of window size from the passengers' point of view.

Then there was the problem of noise. That of one particular turbine was absolutely shattering when taxy-ing out. When there were 20 aeroplanes with that particular engine installed they would clear the public enclosures in record time. Could the engine designers do anything about it?

A low humidity was very valuable to an airline, because it increased the bar receipts —and the bar was one of the most profitable parts of an airline!

The right psychological approach by the flying staff was absolutely vital. He was glad to hear Lady Douglas mention the importance, from the psychological point of view, of the captain of the aircraft walking around and speaking to passengers.

Food was also important, especially for those competing with epicurean arrangements. "Feed the brute" was an airline maxim as well as the housewife's.

The helicopter—an excellent form of "vibro-massage" which was being introduced in increasing numbers — would have a tremendous influence on passenger carrying in the future, and it would be interesting to hear passenger reactions. B.E.A. had heard one or two during the short time they had been operating helicopters.

The problem of the airline was to woo the passengers into the air and, having done that, to keep them "sold" on flying.

D. O. Bustard (B.O.A.C.): When Mr. Huntington began to speak he had been horrified about what would be said because, among the passengers who wrote to express their views, the King's Messengers always seemed the most ready to do so. But their comments were welcomed, because many of the comments made by passengers were, frankly, ill-informed; the comments from King's Messengers, on the other hand, were not, and he did not think there was another group of people in the world who were better qualified to present the passengers' point of view.

Mr. Huntington had said that passenger handling on the ground overseas varied a great deal from station to station. That could be explained, perhaps, by the fact that some stations had a far greater number of aircraft to handle than others, and he believed that the busier stations were getting their staffs licked into shape after the war years much more quickly than were some of the stations which had only a few aircraft to handle. He would like to know whether that could be confirmed by the outside observer.

He also liked Mr. Scott Hall's plea for mental comfort, which was tremendously important. Mental discomfort was possibly as tiring as the noise which Lord Douglas had mentioned. There seemed to be no doubt that the majority of passengers were slightly uneasy when they travelled by air, and he believed that one of the greatest contributing factors was not so much the noise or the horrible headlines that appeared from time to time, but the fact that the passengers

were in unfamiliar surroundings. Everybody knew all about ships and trains, for they had grown up with them, and they accepted communication cords on trains and lifeboats on ships without a thought. But immediately they boarded an aeroplane, the steward pointed out the emergency exits and indicated the safety belt and made sure the passenger used it, none of which contributed to the passengers' peace of mind. A few might not worry, but he believed the majority were disturbed by it, and the fact that they were a little tense throughout the flight was tiring.

It was difficult to determine how to speed up this process of making the aeroplane familiar to the public, but they could go some way towards that end. The Industry accepted guidance from the airlines in that respect, so perhaps the airlines bore the greater responsibility. He did not suggest that they should try to make the cabin look like the inside of a Tudor cottage, but he felt that something could be done. For a start they should get away from long tubular cabins; no-one was accustomed to sitting in a corridor.

Being personally keen on backward-facing seats, Mr. Edwards' statement that they involved a weight penalty came as a surprise and a disappointment to him. Mr. Masefield's objection, that passengers embarking aft would see a lot of people goggling at them as they came through the door, could be overcome by embarking them at the forward end of the aircraft. Passengers would know why the seats faced backwards, but he did not attach much importance to that; after all, they knew nowadays why they must use belts when taking off and landing.

There was little doubt that the public liked flying boats but he would not like to see them back until far more money was spent on marine bases than had been the case so far. If one-tenth of the money that had been spent on aerodromes were spent on marine bases, he believed commercial flying boats would be with them still. He had such vivid and bitter recollections of embarking and disembarking passengers on choppy water in exposed landing areas that he felt sure, to give the flying boat a fair chance, they must spend a lot of money in providing sheltered water.

Mr. Huntington had pointed out that at overseas stations B.O.A.C. employed perhaps two English commercial staff, the rest being local people, who were not very good; and had been kind enough to say that their shortcomings were not the fault of the Corporation. But if shortcomings did exist it was the Corporation's fault. B.O.A.C. employed a great number of local staff overseas nowadays and indeed they had to do so; in some places they were obliged to do so by law. But economically it was obviously necessary to employ as many local people as possible. He believed that on the whole they were good.

The training of staff in passenger service all over the world was a difficult problem, and it would take time to regain the ground that was lost during the 1939-45 War, but progress was being made. Local staffs varied all over the world, but there were no local staffs anywhere which could not be trained to the required standard. The Corporation could make something of them all, and where there was room for improvement the Corporation was taking action.

C. G. Grey (*Founder Member* and *Hon. Companion*): He tendered his sympathy to the designers of the aeroplanes. In a letter that morning, H. K. Jones, formerly of the Hawker Company, referring to General MacArthur, said: "No man can serve himself and two masters." He felt that the position of the aircraft designer was like that, because the aeroplane he would like to design was probably nothing like that which his two masters wanted, one being the passenger, who wanted safety, comfort, and all that, and the Directors of the airline, with their pence-per-ton-mile.

He was sorry that backward-facing seats would cost more because he believed the human frame could take more shock backwards than forwards. In a train he always sat with his back to the engine, because if the brakes were applied suddenly his back pressed into the back of the seat on which he was sitting, instead of being pitched into the seat in front; and if the man sitting opposite were pitched forward, he had two hands to push into his face. Presumably the objection to backward-facing seats in an aeroplane was that it was more pleasant, even at a squinting sort of angle, to look at the country coming towards the passenger than to look at the country receding—Lady Douglas had referred to mirrors, perhaps they could have periscopes—but then again pence-per-ton-mile came in.

With regard to the equipment of the ladies' rooms, a woman friend of his family had arrived recently from Canada, very pleased

with her trip in a B.O.A.C. Stratocruiser. Everything was beautiful except that, when, nearing London, she wanted to make up her face, she had found that other passengers had pinched the face-lotion bottles. He suggested that the airlines might have plastic bottles marked to be taken away as souvenirs.

Of the Stratocruiser with a bar down below an Australian friend who had flown to Great Britain—not by B.O.A.C. he believed—had said that the wise people let the others down to the bar first, while cocktails were free. When they came back to their seats in the cabin, his friend, with another passenger, went downstairs, stretched out on the comfortable lounges, and had a night's rest.

Alec Henshaw, the Cape Town record-holder, said a long time ago that flying was the best means of getting about the world quickly, if one were not in a hurry. The woman friend he had mentioned previously had left Vancouver and, being due to arrive in Great Britain on a Sunday, had actually arrived on the following Tuesday. The air liner from Vancouver could not get into Toronto, but was sent on to Buffalo, New York, where the passengers were imprisoned in the machine because they had no visas for the United States. After several hours they were allowed to go, under guard, to the airport restaurant, and subsequently they were flown to Montreal. From there she had to travel by train to Toronto. Subsequently she had to go back to Montreal and wait there for a day until the machine to bring them to England arrived and was turned round. It had been held up at Gander by snow.

With regard to aerodrome comforts, a friend of his, who had flown all over North America from Alaska to Mexico City and from Seattle to Washington, said that there was not an airport in the world at which a passenger could get a bath and a shave if he arrived after a night's flight and wanted to spruce up and do business in the vicinity, and then fly on again in the evening. Still more astounding, there was not a hotel in London at which, having booked a room, one could arrive in the morning and get a bath, because the bathrooms were built-in with the bedrooms and the bedrooms were not "readied" till noon. So they might forgive the airport authorities.

Contributed: Prestwick Aerodrome protested that it had its own hotel on the ground—and a very good hotel it was to his knowledge—where baths, hot and cold, were on tap at any hour of the day or night.

J. O. H. Lobley (*Associate*): Although a member of one of the air Corporations, he spoke from the point of view of a passenger, having travelled around the world with a number of airlines.

An overwhelming amount of attention had been paid to the design of aircraft seats. He had seen the seats in the production stage, and he had seen the most eminent people in the airline business sitting in those seats in order to try them. He often wondered how often the seats were tried out over a long period of time, *i.e.* by passengers travelling half across the world, with the sole object of testing the seats in which they were sitting.

Unfortunately for him, he happened to have rather long legs, which were always getting in the way when he was sitting in an aeroplane. The first thing he noticed about a seat was its position in relation to the seat in front. Recently he had made a test flight of two hours or a little less in an aircraft which had been re-equipped, and had been surprised to find that, when sitting on the inside seat, he was unable to put his left leg fully forward without turning slightly sideways, so taking up some of the space allotted to his fellow passenger, who was sitting on his right.

The "Argonaut" seat, in itself, was quite comfortable. The difficulty was again, he believed, the inability to put one's legs fully forward. Even in the lecture room in which they were meeting there was discomfort when sitting down, because they could not get their feet forward because of the seat in front.

Having travelled long distances in aircraft fitted with bunks, because he was familiar with flying he was able to sleep. But a number of passengers to whom he had spoken had told him that they had difficulty in getting to sleep. They said that first they had almost to undress in order to put themselves into the mind to sleep, then there was the general excitement of the journey, the vibration and noise and the unaccustomed circumstances, and the net result was that few could sleep. They were pleased to have a bunk available, but he wondered how often a bunk performed the function for which it was intended. On the other hand, there was a case for the fully reclining seat. The passenger was already sitting in the seat; if

it were really comfortable, and if it gave leg room and gave support for the calves, which was important to relieve fatigue, it seemed to him that the passenger was then more likely to go off to sleep in that type of seat. The Corporation with which he was associated had been concentrating on designing precisely that type of seat, and he believed the passengers would be much happier with it in future than they had been in almost any aircraft which had been operating so far.

He was an advocate of the flying boat, having flown those aircraft and having travelled as a passenger in them; there were two, or perhaps three, factors which attracted passengers. First there was the feeling that in the course of a flight over water the flying boat could land with a fair amount of safety, probably more safely than could a landplane flying over land, although with the improved efficiency of aircraft today he imagined that that feeling must be disappearing. The most obvious cause of delight to the flying boat passenger was that the machine took off from and landed on water, frequently in beautiful surroundings, whereas the landplane used aerodromes which were not so good looking. Also, the dust which arose so frequently on aerodromes was not encountered by flying boats.

If they could improve the surroundings of aerodromes and also concentrate on keeping down the dust, they would have done a great deal towards transferring the attractions of the flying boat to the landplane.

J. Lankester Parker (Short Brothers and Harland Ltd., *Fellow*): The only airline he used with regularity was that between Belfast and Northolt, and although the machines used on this route were, he supposed, the least comfortable of all the types in service with the British Corporations, that method of travel compared most favourably with any other method he had used. When he reflected on the struggles he had had, not many years ago, to get to Belfast from London in one piece flying his own aeroplane or on the delays and discomfort as a normal third-class railway and boat traveller, and contrasted that with the present standard of the flying service, he considered it a great tribute to the general development of air travel.

While he confessed to being a most nervous aircraft passenger, when he looked around at his fellow passengers he felt that they too were not all mentally comfortable. They seemed perfectly happy when the aeroplane was flying straight and level, but directly the aircraft started to turn and in conditions which the average passenger regarded as very bumpy, but which he considered to be only slightly so, they became uneasy.

Emphasising the importance of large windows, he pointed out that even on the bad weather routes an aeroplane did not fly in cloud all the time, but above the cloud.

Backward-facing seats were proposed in order that passengers would suffer less injury in the event of a crash, but fire was still one of the greatest causes of casualties, and in a crash which was followed by fire he felt there was something to be said for being laid out immediately. Rather would he utilise the extra weight involved in highly stressed rearward facing seats in some other way to lessen the risk of crashing.

There was much to be said for the tricycle undercarriage, instead of the normal tail wheel type, which would bounce or skid off the runway at the least provocation. A tricycle on the contrary, so long as the first touch down was not bad enough to break it, would "stay put" on the ground and tend to run straight; the importance of this could not be emphasised too much.

He felt he was a little too prejudiced to be able to say, fairly, anything concerning flying boats, but he was glad to hear other speakers express the view that they were not yet dead and that, given better mooring places, docking facilities, and so on, they might well come into their own again.

R. S. Stafford (Chief Designer, Handley Page Ltd., *Fellow*): There seemed to be some misunderstanding about Mr. Edwards' remarks on the weight penalty which would follow if seats faced aft. Mr. Edwards would probably agree that he had meant to say that, if they designed seats for an acceleration of $15g$ instead of $6g$, then there was a weight penalty; there was no weight penalty as such in facing the seats aft. His own sum of the penalty involved came to about half that given by Mr. Edwards.

He liked to be looked after from the time he left a roof over his head to the point at which he stepped into the aeroplane, and again after leaving the aeroplane and until he was under a roof. He was a little critical of the arrangements made for the care and convenience of passengers at those stages.

A few weeks ago, at Northolt, in very rainy weather, a woman passenger who had left an aircraft and who was very lightly clothed, could not get into the 'bus because it was already filled; so that she went back to the aeroplane, to await the next 'bus. By that time she was thoroughly wet.

Lady Douglas had asked for mirrors to be fitted to the backs of seats, but as a passenger, thankful that he had arrived at the end of a bumpy journey without being ashamed of himself, he could think of nothing worse than to have his own green countenance staring back at him!

J. S. Shapiro (Cierva Autogiro Co. Ltd., *Assoc. Fellow*): His main distinction in addressing the meeting was, he believed, that he was the first passenger to take part in the discussion who paid out of his own pocket!

As one who had thought a good deal about conveying passengers by helicopters, and had flown in a large helicopter, he was interested in Mr. Masefield's reference to helicopter travel as a form of vibro-massage. It reminded him of the experience of an unfortunate test pilot who was extremely sensitive to that kind of vibration; indeed, he could well have been put up by the National Physical Laboratory as the standard for the threshold of vibration sensitivity. A particular machine which he was flying did not always behave consistently, and would play around just about and just below the threshold; so that on some days it was marvellous and on other days it was abominable. The test pilot did not express his views quite in those terms. On one occasion his colleagues had played a trick on him. A gadget to register vibration was fitted in the machine, and they had taken it out and fitted it in the pilot's car; it was shown that the vibrations in the car were far worse than those in the helicopter. It was an ordinary 10 h.p. car, having nothing special about it, and the pilot was amazed when he had seen the readings.

Mr. Scott Hall had referred to psychology or mental comfort. He believed that vibration was one of the problems the effects of which they could overcome when they knew more about it, and when they had achieved a certain standard the passengers would not give it another thought.

A suggestion for comfort was that air travel might be sold in the manner adopted by the railways, by providing two degrees of comfort. Would it not be possible to introduce that system into air travel, so that those who travelled on an expense account were able to enjoy the higher degree of comfort, and those who had to pay for themselves could travel cheaply? They would then find out fairly soon what the passengers really wanted, and he believed it would be found that most of them wanted cheap rates.

Naturally he was in sympathy with the designers, because his own experience lay in design. Designers had to go in for compromise. A compromise became very much better and more effective if it could be based on real evidence, which evidence should be such that they could make valuable deductions from it; be believed that something more could be done to obtain evidence which was better than an opinion. He would like to see some kind of passenger reaction research carried on which would allow designers to make decisions which would affect the public in, say, 1958. One of the troubles was that such things required a long time to mature.

However, the question of safety should be determined by some public authority. He did not think a passenger's reactions to safety were reactions to safety at all, but were reactions to mental comfort.

R. J. H. Isaacs (*Associate Fellow*) *Contributed*: Several speakers had mentioned three essentials—comfort, safety and price. For the most part the discussion had concentrated on the first two, while the third had been referred to only as a limiting factor acting upon the others.

Mr. Shapiro mentioned the possibility of introducing different classes of travel, and he would like to enlarge on this aspect of the problem.

When discussing this matter it was essential to bear in mind the fact that they must first "catch your passenger." That was to say, the traveller must be lured on to an airline either at the expense of another airline, or at the expense of a railway or a shipping company.

At present a single, high standard of comfort was provided on all routes whether they were of one hour or two days' duration. They surely must distinguish between the short and long distance passenger. The passenger travelling on short European routes had different requirements from the inter-continental traveller and was, he sug-

gested, often travelling for a different purpose. It was reasonable to assume that the percentage of "tourist" traffic carried by B.E.A. was higher than that carried by B.O.A.C.

The traveller who contemplated a trip, say from London to Paris, had a choice between nearly a day long journey of considerable discomfort by rail or road and sea and a brief air trip. However low the standard of comfort provided in the air, it must still be far higher than that of the alternative routes. Aircraft engines did not fill the cabin with sooty smoke! The factor which would decide which method of transportation was adopted was price.

Could not a much larger percentage of "tourist" traffic be diverted to air travel by providing cheap transport at a lower standard of comfort than at present? For example, no traveller on the Metropolitan Railway expected a restaurant car; why, then, should food be provided on any trip of only one or two hours' duration? Seat comfort on long journeys was, as had been pointed out, of great importance but for a journey of an hour or two surely the most uncomfortable seat—even a wooden bench—would be acceptable if it were provided at a price competitive with 2nd class rail travel? Also if no food were provided, then no table space was required. Finally a shocking suggestion. Did they need stewards on short hauls? Provided that passengers were warned either before take-off or by pilot inter-communication about strapping and smoking precautions there seemed little need to waste one seat on a steward. (Perhaps children would have to be banned from a stewardless craft —and this might even attract some first class passengers on to the more peaceful third class lines!)

A further economy could be introduced by limiting the luggage allowance to tourist travellers. A cut in the fare, although this admittedly would be small, could be achieved by excluding coach transport from the air fare, so that only those wishing to use the coaches need pay for them. Cheap night travel was already provided.

If all this were done the standard of comfort would indeed be low but it would still be higher than that of land travel.

On the inter-continental routes the problem was different. On those, meals, attention and comfort must be provided. At present a first class standard was the aim except on certain large aircraft such as the "Princess" for which, he believed, two classes had been planned.

Mr. Edwards had pointed out the price penalty for such additional luxuries as mirrors. There might exist a demand for de luxe travel on those routes. On those aircraft very considerable comfort would be provided—either bunks or widely spaced adjustable seats for every passenger, and a larger bar and lounge than at present. The machine would probably carry less than its possible payload, and the fare would be considerably higher.

The important thing was to keep each class to its own aircraft. If two standards were aimed at in one machine neither would be achieved.

To sum up, the object of third class, short distance, air transport was to capture custom from surface routes, while that of de luxe travel was to tempt the sybarites away from other airline operators.

Philip G. Lucas (*Associate Fellow*) *Contributed*: Although he was in sympathy with some of the things which had been said, and would particularly like to congratulate Lady Douglas on her concise summary of the Passenger's Point of View from a Woman's Angle, he felt most strongly that far too much stress had been laid on physical comfort.

The title of the Discussion was "Air Travel from the Passenger's Point of View," but surely air passengers' views were not confined to the design of the chair on board or the food and wine they would consume on their journeys?

He believed that safety, regularity, and fares within their means came far higher on their list of requirements than personal comfort.

Travel by air, road and rail could not provide the luxurious transport of the "Queen" liners, and air travel was actually a far more comfortable mode than road or rail because the time element was so reduced.

The passenger was certainly entitled to expect a proper measure of comfort and service, but there was reason in everything, and the actual amenities which provided for physical comfort should be determined by what he could afford to pay. Until air travel could be brought within a far wider circle of society the airline business would never be able to stand on its own feet. With the introduction of high-speed and pressurised

aircraft the air traveller would be given a far greater measure of comfort than could ever be provided by the mere introduction of new interiors in existing aircraft. No one had even mentioned that most obvious fact.

He had been flying all his working life and had probably travelled as a fare-paying passenger as many miles as anyone at the Discussion, so felt qualified to say that the air traveller's needs could be served best by flying more safely, more regularly, and more cheaply.

There were vast numbers of potential air travellers throughout the world who would be flying *now* could they afford to do so, and it was only by concentrating on those three points that such vast sources could be trapped.

Perhaps when all the world and his wife travelled by air, luxurious seating accommodation would be provided for those with long purses, but the majority of the real travelling public would be only too glad to have the frills cut out if, by so doing, air travel could be brought within reach of their pockets.

The President: He was reminded of a Chinese proverb to the effect that the mind could comprehend only so long as the seat was comfortable.

The discussion had been entertaining. It had indicated that, apart from safety and reliability, the personal factor of comfort, both physical and mental, was becoming increasingly important. They had progressed a long way since the days when an old friend of his had said, at a lecture of the Society, that the proper way in which to handle passengers would be to dope them, put them in racks in the aircraft, without heating or feeding them, and then give them a stiff whiskey to put them right again at the end of the journey. In those circumstances there would be no mental stress.

Expressing the thanks of the Society to the opening speakers, the President wished Mr. Huntington good luck and safe landing, and expressed the hope that at some time in the future he would speak further of his experiences, especially about Russian aircraft. Lady Douglas had done extremely well, and the Society was especially grateful for her charming references to those who normally were too little mentioned.

The President also paid tribute to Captain J. Laurence Pritchard, who was attending his last meeting of the Society as its Secretary.

THE DERIVATION AND ESTIMATION OF AERODYNAMIC LOADS FOR STRESSING PURPOSES*

by

D. J. LAMBERT, A.F.R.Ae.S. G.I.Mech.E.†

1. INTRODUCTION

The rational estimation and derivation of aerodynamic loading data is becoming of rapidly increasing importance in the design of modern aircraft. The great advances made in aircraft performance during the 1939-45 War, together with the generally detrimental effect of compressibility upon stressing loads, have combined to make the task of the structural designer much more difficult. A few years ago, the loads resulting from the often arbitrary stressing cases of A.P.970 (Ministry of Supply Air Publication 970, Design Requirements for Aeroplanes for the Royal Air Force and Royal Navy) were of relatively minor significance and furthermore, any inaccuracies in their estimation and derivation were covered almost always by the ultimate factor if the estimate were on the low side, while if the loads were conservative, the weight penalties and structural difficulties involved were small.

The situation is different now. Thinner wing sections and slender fuselages make it almost impossible to cater for the much larger stressing loads with an economic structure. Assumptions are much more difficult to make because of compressibility and other effects and errors in them can be of catastrophic magnitude, while the wide range of equivalent air speed (E.A.S.) and height possible make it difficult to determine the design stressing conditions without an extensive investigation of all the possible flying conditions. Unfortunately A.P.970 has not kept pace with the developments, largely because of a lamentable two-year gap in development in 1946-47. The British Civil Airworthiness Requirements are less open to criticism, first because they are of more recent origin, secondly because they often state the generalised case followed by an acceptable interpretation which may be used if desired, and should be ignored where it is obviously inapplicable, and thirdly because in general (although there may be exceptions) experimental and military aircraft are expected, and designed, to probe farther into the regions of marginal safety than their civil counterparts. This is probably the most important difference.

A.P.970, or at least the parts under discussion, are in the process of radical revision and modification. The J.A.C. (Joint Airworthiness Committee) is largely responsible for this revision and there is no doubt that many improvements can be expected.

The intimate aerodynamic details of most high speed aircraft at the moment are secret but here and there the errors and dangers which can exist in the prediction of loads for such aircraft have been pointed out, and to do this some numerical examples were necessary. Therefore, in the accompanying graphs imaginary values have been used for derivative and compressibility changes. Nevertheless, the general character of the curves and the changes shown are examples of what may be expected on well-behaved high-subsonic aircraft. The actual numbers are valueless but the qualitative results are useful warnings.

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* A Section Lecture read before the Royal Aeronautical Society on 13th February 1951—the 816th Lecture to be given before the Society.

† Mr. Lambert is a member of the Aerodynamics Dept. of Vickers-Armstrongs Ltd., Weybridge.

NOTATION

W = aircraft weight
S = gross wing area
S' = gross tailplane area
$\bar{c}$ = wing standard mean chord (except in Fig. 13)
c' = tailplane standard mean chord
α = wing incidence
l = distance from aircraft c.g. to tailplane aerodynamic centre
g = acceleration due to gravity
h = c.g. position as a fraction of the wing standard mean chord
h_0 = wing aerodynamic centre position as a fraction of the wing standard mean chord
c.p. = centre of pressure
α' = effective aerodynamic incidence of tailplane
η = elevator angle, radians
η_{trim} = elevator angle to trim, radians
η_T = tailplane setting to wing no-lift line
ε = angle of downwash
L_W = wing lift
C_L = lift coefficient
L_T and C_{LT} = tailplane lift and lift coefficient
C_D = drag coefficient
n = aircraft acceleration normal to the flight path, "g" units
p = pressure
q = dynamic head, $\frac{1}{2}\rho V^2$
$C_{L_{gross}} = nW/(qS)$
C_{m_0} = pitching moment coefficient at zero lift (tail off)
m = tailplane C_{m_0} per radian of elevator angle
M = Mach number
$M_0 = C_{m_0} qS\bar{c}$
$M_1 = M_0 + W\bar{c}(h - h_0)$
$M_2 = m\eta qS'c'$
a, a_1, a_2 = lift curve slopes of wing, tailplane and elevators respectively
$d\varepsilon/d\alpha$ = rate of change of downwash at tail per radian of wing incidence
$\overline{V} = \{ S'/(S\bar{c}) \} \{ l + (h - h_0)\bar{c} \}$
$\overline{\overline{V}} = \overline{V} / \left\{ 1 + \frac{a_1 S'}{aS} \left(1 - \frac{d\varepsilon}{d\alpha} \right) \right\}$
V = forward speed (ft./sec.)
V_M = maximum equivalent air speed in level flight (ft./sec.)
n_1 = maximum normal acceleration coefficient
K = a factor in the expression for rolling torque in Sections 5.3 and 5.4 of Chapter 206 of A.P.970
V_D = design diving speed
V_A = design manœuvring speed
b_1, b_2 = rate of change of hinge moment coefficient with incidence and control deflection respectively
c_F = chord of fore flap } of double-
c_R = chord of rear flap } slotted flap
x = chordwise distance of flap centre of pressure from leading edge of flap
ψ = angle of yaw
ϕ = door angle (*See* Fig. 13)
C_H = hinge moment coefficient (*see* Fig. 11)
L = lift (except in Fig. 13)
Force coefficient on fore flap = (force/ft. span)/(qc_F)
Force coefficient on rear flap = (force/ft. span)/(qc_R)

2. AERODYNAMIC LOADS. FUNDAMENTAL ASPECT

Aircraft are designed to fulfil certain duties; to carry an object or objects between two points a specified distance apart, or to support some animal or animals, usually human, for a specified time, in which case the aircraft is expected not only to support its occupants, but it must make the appropriate evolutions desired of it. Clearly the optimum structure for such an aeroplane is one which provides sufficient strength for those duties and the incidental business of getting off and back on to the ground should not be permitted to interfere. This is an ideal and one which at the moment seems impossible to approach. However, it does emphasise that the structure should be designed upon a rational interpretation of what the aircraft is required to do and is likely to do. To have requirements which simultaneously provide safety for trainers and bombers is ridiculous but perhaps understandable. Such requirements seem to have sprung from the erroneous impression that the time spent in evaluation of loading data should be kept to an absolute minimum; but it must be remembered that when these requirements originated, the penalties for such arbitrary assumptions were relatively slight. Now they can be completely crippling. A large proportion of the

structure of an aircraft is designed by the operations of take-off, landing and general ground handling. Many have commented and complained that undercarriages provided for take-off and landing represent unduly large proportions of aircraft weight, but few, until fairly recently, have complained that large portions of fuselage, engine mountings, and so on, may be designed by these same landing manœuvres. It would be a pleasure to look forward to the day when ground control and pilot instrument aids, coupled with really good aircraft control and handling characteristics, will guarantee landing and take-off operations which do not even design the undercarriages. These will be designed by the "standing at rest" case. Obviously this is a "pipe dream," yet its partial attainment would mean a tremendous stride in progress towards more efficient aeroplanes.

3. RESPONSIBILITY FOR STRENGTH REQUIREMENTS

There are in Great Britain two sets of official requirements which contain flight stressing conditions—The British Civil Airworthiness Requirements for civil aircraft and A.P.970 for military aircraft. In general, their requirements are similar, although there are some fundamental differences which will be discussed later. The object of all such requirements is to ensure adequate, but not unnecessary, strength. In the first object, few will deny that they are successful, as the number of proven cases of structural failure as a result of unsatisfactory loading requirements is very small. The achievement of the second object, to say the least, is controversial. However, if a designer feels that on his particular aeroplane under the proposed mode of operation, the application of any of the loading cases is unnecessarily severe, then he may be assured of a sympathetic hearing from those responsible. In fact, there is a good chance that not only he but others, too, will benefit by a reduction in the severity of the actual requirements.

Alterations to the military requirements may come about in a number of ways. There may be a number of appeals from different manufacturers to the Director, Royal Aircraft Establishment, for concessions in a particular case. These are considered by the Structures Department and it may be that they indicate a common feature of severity. If their case is incontrovertible, it is usual for the Structures Department to prepare a paper for submission to the J.A.C. (on which the Society of British Aircraft Constructors, the Ministry of Supply and the R.A.E. are represented). If the change is approved, the machinery is set in motion for amending A.P.970. At the present time it takes about twelve months for the amendment to pass from J.A.C. approval into A.P.970. Bearing in mind earlier deliberations and the rate of aeronautical development, it can be appreciated why amendments are sometimes a little outdated when they appear.

As often happens, the reasons and evidence supporting a change in the requirements are by no means incontrovertible and then it is usual for the J.A.C. to form a working subcommittee to give the matter full and technical consideration. The findings of the sub-committee are submitted to the J.A.C. and from then on the procedure is as before.

Occasionally, but fortunately rarely, attention is drawn to the failings of a requirement by an accident or a number of incidents indicating inadequate strength. Once again it is usual for a sub-committee to ponder the evidence.

If important changes are probable, the Air Registration Board is invited to have a representative present at the meetings so that consideration can be given to the need for complementary changes in the Civil Requirements.

Much the same procedure for changes is in use by the Air Registration Board but as this is a more independent body which does its own printing, the delays in the publication of an amendment are considerably reduced.

The A.R.C.C. (Airworthiness Requirements Co-ordinating Committee) occupies a similar position in civil aviation to that of the J.A.C. in military aviation (*See* Fig. 1).

4. THE INTERPRETATION AND APPLICATION OF THE REQUIREMENTS

Until recently the number and simplicity of the requirements was such that the average aeronautical engineer could interpret, assimilate and apply them without previous specialised experience or training. He could be confident that his interpretation would be the right one and he knew that from the data and information available, others would have drawn the same conclusions as he had. When the main flight loads were required it was a simple matter for either a knowledgeable stressman or "the man who did the

performance" to estimate all that was required in half an hour or so. Controls were stressed to the A.P.970 rule of thumb. Flaps were negligible, shock waves with their attendant large pressure differences almost unknown and the Handbook of Aeronautics provided all that was required in the way of pressure distributions. The situation has changed considerably now. It is by no means every aeronautical engineer who can understand the requirements, fewer would embark upon their interpretation and, in the present state of "compressible indecision," the task of actually assessing flight loads is almost inevitably an aerodynamic one. It is not to be expected that the modern stressman should be able to give the compressibility effects on C_{m_0} and h_0, $d\varepsilon/d\alpha$ and a, their proper attention.

In Figures 2 and 3 are shown the type of compressibility effects which are by no means uncommon. The theoretical compressibility effects assumed were:—

C_{m_0} Glauert on wings; effect on fuselage negligible.

a, a_1, a_2, $d\varepsilon/dC_L$ Linear Perturbation Theory.

The predictions shown may be described as very good for first stress purposes on a new machine. For check stressing and/or a new design basically similar to a previous one, the peaks and changes of curvature should be much more accurately predictable.

In Fig. 4 are sketched some values of C_{m_0} tested at various Reynolds numbers, in some cases by the reflector plate method.

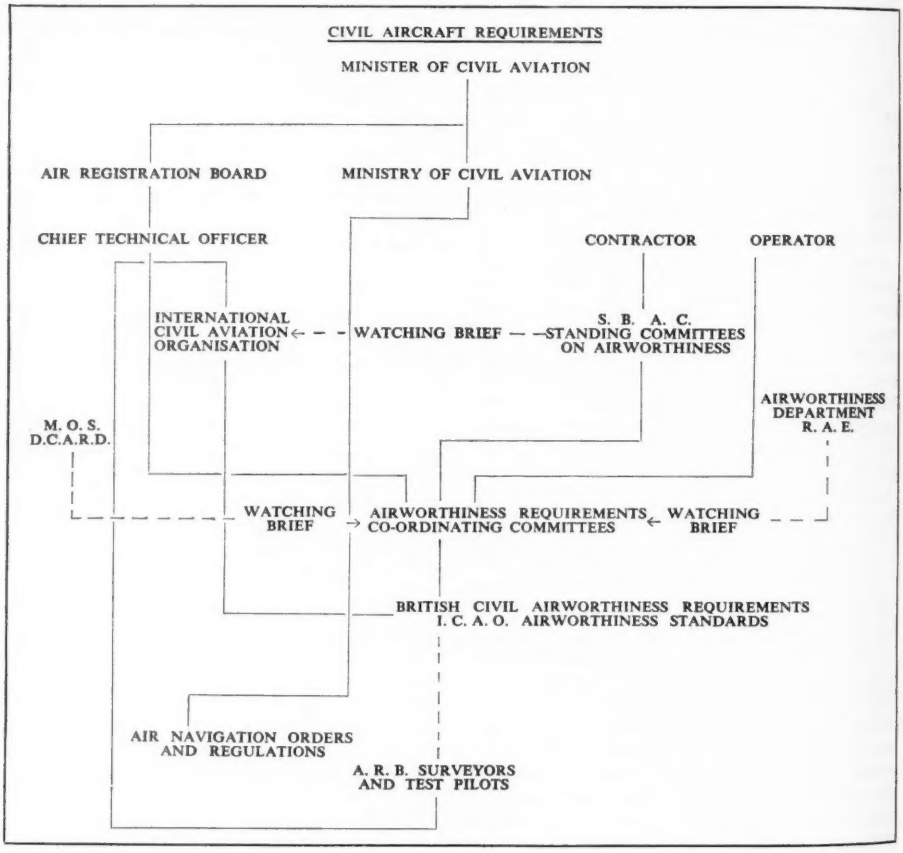


Fig. 1.

The range of values of C_{m_0} is interesting and, when it is remembered that some aircraft have to be designed on just one or two tests, the possible errors are alarming. The main differences are probably due to Reynolds number, but some doubt must be thrown on the half-wing tests. It is difficult to arrange a fully floating model upon which forces can be measured without having a leak between the model and the tunnel wall or floor. A small leak can have a significant effect upon the body contribution to C_{m_0}. It is difficult enough for the experienced aerodynamicist to assess the relative merits of three separate tunnel tests giving the same peak value of C_{m_0} at three different Mach numbers; for the non-specialist it is impossible. On the other hand, the day to day problems of the practical aerodynamicist have increased in number and complexity to such an extent that he is seldom in a position to investigate the question of aerodynamic loads as thoroughly as it should be investigated. Edwards[1] in his paper indicated the rising proportion of aerodynamicists in aircraft firms. Among that number there is, or should be, developing a race of hybrids. These are people who devote the major part of their working days to the estimation, derivation and rationalisation of flight loads.

Essentially aerodynamicists, they must have developed a knowledge of stressing and stress office procedure and be able to appreciate the structural significance of aerodynamic phenomena and translate such phenomena into tangible tons or tons inches. Because they spend a major portion of their time on the subject they should become adept, even expert, at the interpretation of stressing cases, and they will learn rapidly what sort of changes and modifications are likely to have significant effects and will be on the look out for them.

A non-professional estimator of flight loads cannot be expected to concern himself with fundamental deficiencies of an arbitrary method of estimation. Probably he will not enquire "why" if he can help it and he is unlikely to compare the results on one machine with those on another, *having proper regard* for their differing characteristics. Much valuable design information can be obtained if the stressing cases are pursued to their logical conclusion and much better and safer aeroplanes can be made without any added complication of the

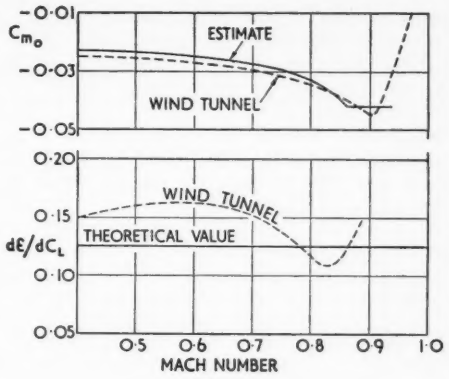


Fig. 2.
Typical compressibility effects.

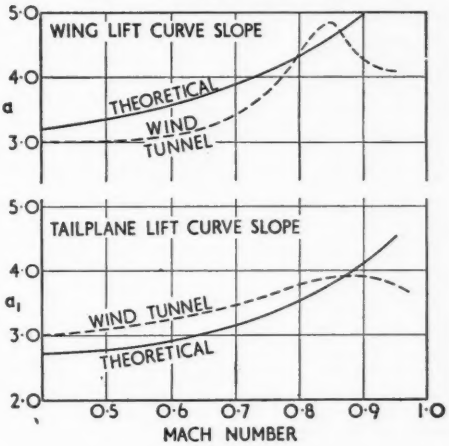


Fig. 3.
Typical compressibility effects.

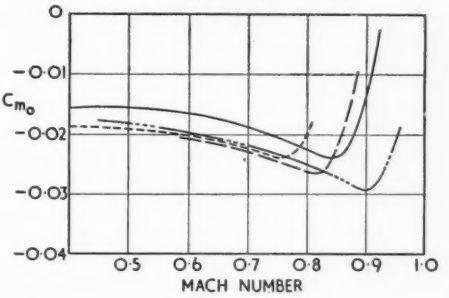


Fig. 4.
Variations in wind tunnel C_{m_0} measurement.

——— Half wing and body R. No. $\simeq 1.5 \times 10^6$
— — — Half wing and body R. No. $\simeq 0.5 \times 10^6$
— · — · — Wing and body R. No. $\simeq 4.0 \times 10^6$
- - - - - - - Wing and body R. No. $\simeq 0.25 \times 10^6$

structure itself if *all* the important parameters in the stressing cases are appreciated.

The task of these "hybrids" extends beyond the interpretation and application of the requirements. Their proper home is the aerodynamics office but greater liaison must be maintained with drawing and stress offices than has hitherto been attempted. Liaison with the stressman is obviously essential. He has to use the loads and he should be able to make the "hybrid" understand why it is that a certain load is unacceptable, not so that the case may be "arranged" but so that fair and proper thought may be given to the case, its history, the reason for its inclusion, whether such a reason remains valid in the particular circumstances, and whether, by an otherwise insignificant modification to the aircraft characteristics, the severity of the case in question can be reduced. It is only from a knowledge of the structure and the type of conditions which may prove to be serious for it, that the most severe practical design conditions may be assessed. On the shrouds of internally balanced ailerons, for example, the loads when a shock wave is positioned at the trailing edge of the shroud can be serious, as will be seen from Fig. 5. In the case shown, the mean loading on the shroud is at least $0.35q$ with the possibility that the relieving pressure inside the shroud may be much less than assumed, thus raising the resultant loading to $0.5q$. At sea level a Mach number of 0.9 represents a value of q of about 1,200 lb./ft.^{2} and thus the unfactored load on the shroud would be 600 lb./ft.^{2} or over 4 lb./in.^{2}. Coupled with severe wing bending in the high-speed rate-of-roll case the shrouds may wilt visibly, but it may be a totally different and innocuous looking condition which designs the trailing edge member to which they are attached. In a specific example, the negative stall case, coupled with the low-speed shroud loading, designs this item.

Liaison with the drawing office can be similarly justified. A knowledge of the structure and the design problems therein is extremely useful. It enables a balanced outlook to be maintained. Often without weight penalty, arbitrary and knowledgeably safe figures can be quoted for loads or pressures without tedious analysis, but without a knowledge of the general implications of an informed guess, it is most unwise to make one. It is not suggested that the day to day work of a design office should be done on committe lines, but intelligent discussion of all aspects of a problem must lead to improvements in design. The system of concessions to the production departments is an example of what should, and can, be done between the aerodynamic loading section and the structures people.

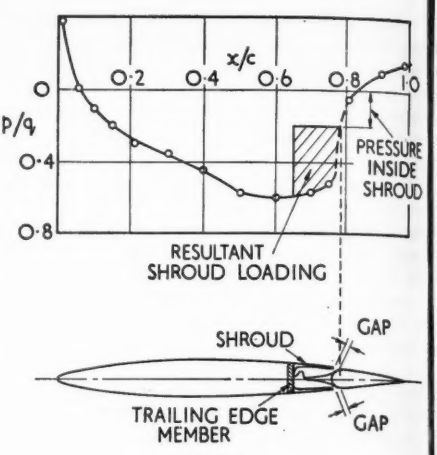


Fig. 5.

Symmetrical aerofoil, upper surface pressure distribution $\alpha = 0°$ $M = 0.9$.

If there is much to be gained by an alleviation, as indicated by discussion, then steps must be taken to see if that alleviation can be achieved by aerodynamic means. (Such means are sometimes professional secrets but the obvious type of thing that can be done is the heavying-up of a control to prevent dangerous angles being achieved, the venting of a compartment upon the skins of which large and unwanted differential pressures occur, and so on.)

Opinion seems to be divided upon the merit of making rigorous and detailed investigations of the aerodynamic loads to be expected on a new design. One school of thought argues that the present empirical laws have usually produced sufficient strength in the past and that they should be allowed to continue in being until they are shown, practically, to be inadequate. They argue further that not enough is known about what really happens for satisfactory predictions to be made, and that the rigorous investigation of all stressing conditions will result in loads being increased and thus, the all-up weight.

They are wrong. It should be the duty of an aircraft designer, as it was of the old craftsman, to see that his job is completed to the best of his ability. The duty of the aircraft chief designer extends to the employment of people of higher specialised ability to tackle all the problems associated with his design. It is his duty to use these specialists upon all the new problems which have arisen in the past few years. The strength side is no less important than the flutter and the aeroelastic distortion aspects.

5. INITIAL LOAD ESTIMATES

Load estimates in the early stage of design are of much importance in reducing the margin of error in the basic assumptions of structure weight and configuration. One of the most neglected avenues of profitable investigation is that of wing camber. All too often the wing section of a new aeroplane is decided without any reference to the balancing tail load which will be required. It may be that the stiffness criteria on conventional layouts at high equivalent air speed are such as to demand structure which can cater for the tail loads as an incidental. The stiffness criteria themselves are not by any means exempt from the general criticism of antiquity and any designer finding his structure dictated purely by stiffness would be well advised to investigate the actual requirements more closely. Whether he will then find the requirement to be unduly severe or just the opposite, depends upon the configuration, but in any case a valuable investigation will have been inspired.

For the problematical advantage of a possible small increase in $C_{L\max}$ at high Mach numbers, a number of designers have been left with values of C_{m_0} which ultimately have caused them much embarrassment. A little more thought and very little more work in the early stages would have shown them the significance of their choice and probably they would have altered their views. Recent information on $C_{L\max}$ against Mach number lends little support to the belief that camber improves $C_{L\max}$ in the high subsonic range.

Gust normal accelerations rank with tail loads as the most important quantities to be evaluated in the early stages. There is no need for detailed calculations of lift curve slope and downwash before rough loads can be given, but once the rough assumptions have been made the usual series of aspect ratios, wing loadings, and so on, which are considered at the birth of a design should be assessed, having proper regard for the effect which they have on the loads which ultimately must be withstood. As Ref. 2 shows, large aircraft may have a wing frequency equal to, or less than, the gust frequency. In such cases the gust alleviating factors are dangerously optimistic.

6. FIRST STRESS DATA

Once a design has advanced sufficiently for a first stress to be started, aerodynamic loading data must be available. Preliminary estimates of the main aerodynamic derivatives will have been completed and some of them may have been checked by wind tunnel measurements. The first data to be issued should cover the symmetrical flight envelope and gust cases at fore and aft c.g.'s and maximum and minimum flying weights. Care should be taken to cover the extreme possible ranges of c.g. position and all-up weight when issuing the first stress data. It often causes a disproportionate amount of difficulty if loads have to be increased by even five per cent. at the check stress stage because of undue optimism in forecasting the earlier loads.

When the work on the primary structure is under way, based on the initial data mentioned, the remainder of the aerodynamic loads must be estimated and issued. Control loads are probably the first priority, although it may be advisable to postpone their estimation for a while, as final or even semi-final control configurations take some time to arrive at and are liable to modification.

Engine mounting loads and flap loads are next on the list and then come door loads, in a class of their own because they look so simple, but in actual fact they are some of the most difficult to calculate. They include bomb doors, chassis doors and camera doors. Some are curved and effectively spoiled by bumps or blisters, some are toed in and some toed out, some open through 180° and then come back to 90° and so on. It is significant that the empirical formulæ of A.P.970 have not been included in Volume 2 and in due course they will disappear and no alternative but tunnel tests will remain. A properly arranged series of basic tests[3] can provide a good deal of useful data, and will be discussed later.

Cabin tops, blisters, drop tanks, and so on, do not often provide difficulty in the derivation of loads; imagination, experience

and someone else's tests are all that are required. (The order is not necessarily one of importance.) With drop tanks at least, there are some severe structural problems which the aerodynamicist must try to relieve. The basic trouble is that from a compressibility point of view a thin strut is essential and there is little base upon which to take out the side loads and accelerations.

When all the first stress data has been issued, more detailed consideration can be given to those aspects which, from discussion with the stressman, are seen to be of most significance. It may be possible by aerodynamic device to reduce loads. Perhaps a detailed investigation into the response of the aircraft during some manœuvre may be shown to be advisable and the resulting figures may permit a reduction in the previously arbitrary stressing cases. An investigation of aeroelastic effects may show that stiffness criteria may be relaxed. An extra aerodynamicist will quickly pay for himself if his efforts result in a saving of weight of even 50 lb. on a civil air liner, although the taxpayer, not the firm, may be the sole beneficiary. In fact, at 1s. 6d. per ton mile, 250 m.p.h. and 2,500 hours utilisation, the 50 lb. saving represents an annual salary of £1,020.

This is an aspect which is all too often ignored and arbitrary loads are some of the worst offenders because they must be on the safe side. Once they cross the line they become obsolete and if vigilance is relaxed for a moment new arbitrary requirements are suggested. An example of this was the move to cater for automatic pilot failure by the increasing of the speed for n_1 in the symmetric flight envelope to $0.95V_D$. However, vigilance had not been relaxed in that case. Probably many aircraft designers would have accepted the proposal with its resultant structural penalties rather than make a rational investigation of the results of automatic pilot failure. The actual structural penalty if this requirement had been applied to a contemporary civil transport of 50,000 lb. all-up weight would have been an increase in design tail load of about 10 per cent. The estimated weight of stiffening to meet the new load was 25 lb. For a given all-up weight this represents £500 per annum less revenue per aircraft, on the assumptions quoted previously.

There are usually many different mass distributions possible at any given weight of an aircraft. From the fuselage bending aspect it is difficult to determine by inspection which gives the most severe case. The different pitching inertias will result in different angular accelerations for a given tail load and when the vertical and angular inertia loads are combined with the aerodynamic tail load any of the three terms may be dominant. In any case, the front fuselage is likely to be designed by a case having a different mass distribution from the case designing the rear fuselage.

Whether or not detailed investigation of every case is justified is doubtful. Undoubtedly slightly more severe conditions than those assumed may be found sometimes, but if the original cases were chosen with care and from experience the percentage increase would be small and could be ignored.

Revised aerodynamic data resulting from more accurate or detailed calculations and from further wind tunnel tests will become available progressively during this stage of the design and a difficult decision has to be made in deciding whether or not the new data will be incorporated. The first essential in a designer's mind is usually "get the prototype flying." Few can argue with the wisdom of this watchword if there is going to be time for structural alterations before the production machines come along. It is not unknown for a production order to be given before a prototype has flown, and thus the earlier that the decision to modify is taken the less will be the interference with the production programme.

The sheer success of a given aircraft is in itself often responsible for exposing weaknesses which, had the rigours of operational life not been contended with, would never have been revealed. Sometimes the failings of a particular design result from a decision made early in the life of the design when the available data was scanty. Aircraft design is often described as "an art not a science" and many such decisions have to be taken. Failings are not justifiable, however, if they would have been exposed by a reasonable amount of searching analysis in the early stages. It is difficult to draw the line between what is, and what is not, reasonable design analysis, and work that is justified on one machine may not be justified on another; however, it is fair to generalise and say that much more work must be put into load estimation in the future than hitherto.

On the credit side there is the knowledge that if a complete and honest consideration has been given to all aspects of flight loads and their estimation in the design stage of an aircraft, and conscientious efforts have been made to check the assumptions with flight data as they become available, then when the time comes for the weight to be increased, the speed to be boosted, or the c.g. range extended, any of these may be attempted in confidence and perfect safety because the appropriate structural measures to be taken will not only be apparent, but correct. One important error which can occur and which is most serious when increased speeds are contemplated, is in C_{m_0}. There are much greater variations in low speed C_{m_0} between estimate or tunnel measurement and full scale than hitherto has been expected.

7. CHECKED LOADING DATA

When a check stress is made it is, or should be, in accordance with a definite procedure. To quote from one Handbook: "The qualifications, experience and number of the technical and design staff employed on aerodynamic and structural design and calculations shall be adequate in the opinion of the D.A.R.D. to conduct the whole of the work involved in investigating and checking designs for compliance with A.P.970, A.D.M.'s, M.O.S. specifications and other relevant instructions. An independent check shall be made of all calculations..." This is not always extended to incorporate the aerodynamic loads, although obviously they also should be rigorously checked. As indicated previously, all the assumptions must be reviewed and the data checked and then someone other than the person who calculated the first set of loads must re-estimate them. To ensure that comprehensive checking is done and that no old data is used in the check stress, the data should be issued in the form of internal reports from the aerodynamics office, and it should be a rule that stressmen must not work to loads which have not been issued officially. The numbers of the reports upon which the check stress was based should then be included in the Type Record.

It is important to have a satisfactory system whereby modifications to aerodynamic loads are properly recorded and issued. The estimators' "say so" must not be recorded on a corner of a sheet of paper, incorporated in the calculation in hand and then destroyed.

As a result of the later calculations and estimates it may be that the original estimates are significantly exceeded. If this occurs then obviously serious thought must be given to determining whether or not they will be approved and worked to, or slashed and adjusted so as to reduce embarrassment.

Both courses can be justified in specific instances. If the increase results from an obvious error in the first stress calculations and is of significant magnitude, then either it must be faced and the structural consequences bravely borne, or much ingenuity must be brought to bear to reduce it legitimately.

Alternatively, the increase may have resulted from someone else's interpretation of the available data. In this case it is much more difficult to support and justify the increase.

The increases may result from an assortment of causes, increased C_{m_0}, altered c.g. range, increased moment of inertia, revised compressibility assumptions, and so on. When the increase comes in this way clearly it must be accepted and worked to. Morally most people will agree, but in practice it is difficult—and understandably so—to increase structure strength at the check stress stage. Thus great care must be exercised in the early stages so that the chances of such load increases are kept as low as possible.

8. FLIGHT TESTING AND CHECKING

Apart from stability and control, nothing can be more important from the safety viewpoint than the strength during the normal flight testing of an aircraft. Perhaps this is in the wrong order, some over-balance or instability can be coped with, but not a failure of primary structure. It is obviously of fundamental importance to check the loading as rigorously as the control and stability characteristics are checked. So far little has been attempted on these lines, but it is rapidly becoming more and more important, and more people are taking a practical interest in it.

Once an aircraft starts its serious tests the designers and the flight test department are much too occupied with their troubles and the number of routine checks which have always been made on prototype aircraft, to go and look for trouble such as abnormally large tail loads, ailerons being more powerful

and lighter than predicted in the design stage and thus suffering much greater stresses, and so on. It is only when something comes off that they turn round and say: "Why didn't you have it checked?" If something has gone wrong much delay is caused which might have been avoided if more checks had been made by the manufacturer in the early stages.

Checks which should be made in the early life of a new design, but which are not called for specifically at the moment are:—

(*i*) *Tail loads.* The science of electrical strain gauge measurement in flight has now advanced so far that the checking of stresses in primary structure should be a simple routine task. A fair check on tailplane loading by way of C_{m_0} and aerodynamic centre can be made by strain gauging to measure, qualitatively only, the bending moment at two or three spanwise positions on each tailplane, thus providing tail loads varying from positive to negative through the speed range. Strain gauge readings can be plotted against speed for several c.g. positions and the speed (*i.e.* C_L) for zero bending moment or tail load can be found in each case from this data. Care must be taken in checking the c.g. position and if possible it should be kept constant in flight by moving ballast as fuel is used.

The basic equation is:—

$$L_T l = M_0 + L_W (h - h_0)\bar{c} + M_2 \qquad (1)$$

or

$$-M_0 = W(h - h_0)\bar{c} + M_2 \quad . \quad . \qquad (1a)$$

at zero tail load.

Two or more sets of values for equation (1) or (1*a*) can be obtained and the values of C_{m_0} and aerodynamic centre position calculated, with no necessity for using estimated aerodynamic data other than to obtain the second order correction of M_0 due to tailplane/elevator configuration. This data, once obtained, proves invaluable in the reduction of other flight results. It is advisable to measure tailplane bending at two or three spanwise positions on one half tailplane to ensure that zero bending and zero tail load are roughly synonymous and a measurement on the other tailplane should be made to check for asymmetry. If there is asymmetry, then the mean of the readings for the two sides should give satisfactory results.

A typical set of flight results is shown in Fig. 6. In view of the increasing speeds of

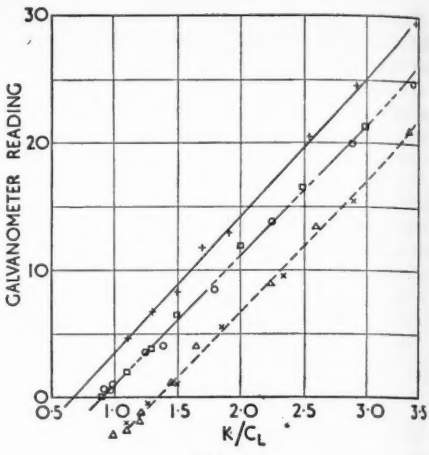


Fig. 6.

Flight test C_{m_0} measurement.

——— c.g. = 0.18 S.M.C.

— - — - — c.g. = 0.215 S.M.C. (two flights)

- - - - - - c.g. = 0.285 S.M.C.

aircraft the check on tail loads is most important. A small numerical error in C_{m_0} which would have been swamped on the last generation of aircraft, can be positively dangerous now.

(*ii*) *Internal pressure measurements.* Both from the point of view of safety and performance, pressures in the various compartments of the structure should be measured. The loss of inspection panels, doors, and so on, in high speed flight is not always attributable to faulty maintenance. Small leaks at critical points on the wing or fuselage can cause unexpected pressure differentials to occur across the aircraft skin. The more frequent use of bag fuel tanks makes this pressure check even more important. Increasing use is being made of venting to get rid of large differential pressures. From the performance point of view, this can be disastrous if proper sealing is not effected everywhere but at the vent. Leakage through the skin joints on the wing or at fillets, can trigger off premature stalls and adversely affect the normal stall and maximum lift characteristics. To ensure that vents are doing their job effectively, the rate of change of pressure with time in various manœuvres can be investigated while pressure measurements at different aircraft attitudes will indicate whether the pressure at the vent is

actually determining the internal pressure, or whether an undisclosed leak is spoiling the plans of the designer.

Some of the things which can, and do, go wrong and which are at present liable to be forgotten are:—

(*a*) The ailerons, designed and stressed in good faith to the out-of-date requirements, are branded by the pilots as too heavy. The remedy is to lighten them. Does anyone worry about the revision of the aerodynamic loading data? Often the answer is no, with a result that perhaps three or four years later, when under combat conditions, violent evasive action is attempted, angles beyond those stressed for are applied, and failure occurs.

(*b*) In the search for good stall warning and behaviour, a hefty tail buffet is obtained. Does anybody worry? When this was first written, the answer was no, but people are becoming more interested in this now, as a result of experience, which, fortunately, has been obtained without personal injury.

(*c*) Pilots ask for permission to use take-off flap angle at high equivalent air speed in descent, to obtain a more rapid rate of descent. The flaps are checked for strength, but is the tailplane?

It is becoming more and more apparent that the strength of high-speed aircraft should be re-considered after they have flown and perhaps the design speeds adjusted. This will put an even greater load on to the flight testing organisation. Bitterly as the salesmen may regret it, the amount of flying time put into aerodynamic checking of the aircraft must increase.

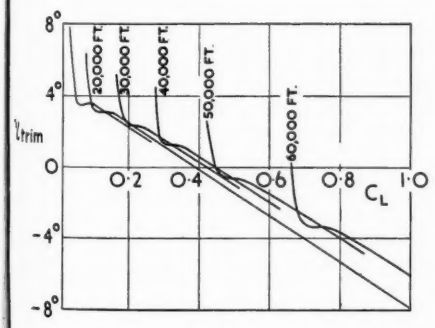


Fig. 7.
Variations in elevator angle to trim.

9. DETAILED LOADING CALCULATIONS

9.1. THE LONGITUDINAL BALANCE CALCULATION

In the old days, this involved no complexity. The aircraft was assumed to be tailless until the pitching moments on the machine were evaluated, and then division by the tail arm provided a satisfactory tail load. Tail couples or centre of pressure position were taken care of by arbitrary c.p. positions and pressure distributions. As a result of an accident, it was found, to many people's surprise, that the position of the elevator was significant, and as a result, the superficially meaningless formula of A.P.970 appeared.

$$M_2 = \frac{lmc'}{a_2 l + mc'}\left(\tfrac{1}{2}\rho a_1 S' V^2 \alpha' - M_1/l\right) \quad (2)$$

While this is a well meaning formula, it seems much more satisfactory to work from the elevator angle to trim, which should always be obtained, for purposes of checking with trim curves produced by the stability and control section.

This value of M_2 should be included with the loading estimates, and allowed for in the balancing tail load. Estimation of M_2 as shown, is only approximate, and on high-speed aeroplanes it should be worked out more accurately, from the elevator angle to trim.

i.e. $$M_2 = \tfrac{1}{2}\rho V^2 c' S' m \eta_{trim} \quad . \quad (3)$$

In the absence of tunnel tests (which are dubious anyhow) probably the most suitable way to arrive at η_{trim} is from equation (4). This formula makes no approximations, except that the effect of tabs is ignored. It has the merit of allowing for the pitching moment due to M_2.

$$\eta_{trim} = \frac{1}{\overline{\overline{V}} a_2 - S' c' m / S\bar{c}}\left[Cm_0 + C_{L_{gross}}(h - h_0) - \right.$$
$$\left. - \overline{\overline{V}}\left\{ \frac{a_1}{a}\left(1 - \frac{d\varepsilon}{d\alpha}\right) C_{L_{gross}} + a_1 \eta_T \right\} \right] \quad (4)$$

Having obtained η_{trim} accurately, the tail-plane lift coefficient, and thus tail load can be obtained with similar accuracy from equation (5).

$$C_{LT} = (1/\overline{V})\{ C_{m_0} + C_{L_{gross}}(h - h_0) + $$
$$+ S' c' m \eta / S\bar{c} \} \quad . \quad . \quad (5)$$

It seems that the value of M_2 should always be quoted in preference to c.p. position, firstly because it is the basic quantity and secondly, because the value of c.p. at infinity with zero tail load always seems rather ludicrous and is valueless to the stressman.

The prediction of M_2 for high Mach numbers is difficult. The first trouble arises in the trim curves which may be expected. Fig. 7 shows some typical curves as measured in a high-speed tunnel. It will be seen that at low C_L and high Mach number, there may be errors of perhaps two or three degrees, or even more, compared with the estimates based on the normal laws. On a machine of the size of the Comet, the tailplane couple per degree of elevator at 500 knots E.A.S. at $M = 0.9$, is likely to be of the order 60,000 lb. ft. Assuming a symmetrical wing section, the corresponding tail load would be, perhaps, 30,000 lb. and so an error of 2° in elevator angle to trim—which is more than likely if normal compressibility corrections have been used in the estimate—would mean a 2 ft. shift of tailplane c.p.

In this estimate the Glauert correction on m has been assumed for the tailplane with a low speed value of 0.5 per radian. In general this errs on the safe side, but it is not easy to justify less severe assumptions.

The kinks in the elevator-angle-to-trim curves are attributable to the type of characteristics shown in the earlier figures, one culprit in particular being the downwash.

Another effect which should be considered is the loss of elevator efficiency due to aeroelastic distortion. This may increase the elevator angle to trim and thus, the tail couple M_2.

Although many people will say that the loads cannot be estimated when the aircraft is obviously flying at, or above, the critical Mach number, it is highly likely that many aircraft of the future will be operating under just such conditions. Therefore, an attempt must be made, and provided that rational and not empirical methods are used, the slowly accumulating pile of data will one day produce the right answer.

A satisfactory form for the loading envelope data is shown in Table I for "Before gusts and manœuvres," and "During gusts and manœuvres."

C_L is quoted only to ensure that the correct pressure distribution is used by the wing stressmen. The wing lift is given to avoid any inaccuracies in its estimation from C_L, and to ensure that n, which includes tail lift effects, does not cause errors.

TABLE I*

Before Gusts and Manœuvres

Case	Speed E.A.S.	M	n	Wing				Tail load to balance	Tail couple	Pitching Acceleration
				α	C_L	C_D	Lift: lb			
50 ft/sec. gust										
25 ft/sec. gust										
A										
B										
b_1										
C etc										

During Gusts and Manœuvres

Case	Speed E.A.S.	M	n	Wing				Tail load to balance	Tail couple	Pitching Acceleration
				α	C_L	C_D	Lift: lb			
+50 ft/sec. gust										
−50 ft/sec. gust										
+25 ft/sec. gust										
−25 ft/sec. gust										
A										
B etc										

*A, B, b_1, C, etc., as per A.P. 970, Chap. 201, from Basic Flight.

9.2. Dynamic pitching calculations

The inclusion of the pitching angular acceleration is essential. In the case of gusts it is difficult to decide what to do, as present knowledge of gust build-up is scanty, but it must be considered. Firstly, because it draws attention to the significance of the gust case from the pitching inertia point of view (and on the front fuselage, particularly of a pressurised military aircraft, the vertical acceleration and angular accelerations, in all probability, will be additive and constitute the most important flight case). Secondly, the consideration of the angular accelerations during a gust, will occasionally inspire a genuine investigation of what really does happen. More data will be obtained, a refreshingly practical approach to one of the accepted empiricisms will be fostered and nothing but good can accrue.

The subject of angular accelerations has been badly neglected in the past. This is amply reflected in the requirements, both military and civil. How should the angular acceleration have been estimated for the yawed flight case in which by some peculiar mischance the machine is found flying steadily at say 10° yaw at 200 knots with rudder neutral? And what should be assumed about the 1.2 angle of equilibrium in yaw, contained in B.C.A.R.'s? The only place where angular accelerations are squarely faced is in the pitching manœuvre cases, and, ironically, these are so ill-founded that pitching manœuvre loads on high-speed aircraft are negligible, while their slower counterparts labour under angular accelerations of the highest.

The pitching or elevator manœuvre cases common in principle to A.P.970, B.C.A.R.'s and I.C.A.O. and C.A.A. are in the author's opinion perhaps the most unsatisfactory loading requirements of the many dubious ones. They are manifestly incorrect in form, they make no allowance for control feel or movement (or elevator effectiveness), and unlike some other cases, it is irritatingly difficult to suggest a practical improvement. Proper allowance must be made for the aircraft characteristics, even though it will undoubtedly mean a more complicated requirement. It has already been remarked that if the existence of such a requirement draws the attention of the designer to the important parameters governing the application of manœuvring tail loads, then its existence will be amply justified. Spring tabs are common upon the controls of contemporary aircraft. Their *advocates* admit that the controls lighten off at high speeds but it is seldom, if ever, pointed out that at high speed they may bring the stick force per g down to a level which permits twice the design g to be applied with one hand, or the tail to be broken off with rapid elevator movement. Those who have done calculations of the effect of auto-pilot "runaway" at various forward speeds on a machine with spring tabs, will appreciate this point.

There is no doubt in the author's mind that the manœuvre loads should be related to pilot or auto-pilot effort, and then due allowance will be made automatically for the variations which can be expected with spring tabs, artificial feel, and so on. Furthermore, the designer will be steered in the direction of safer control characteristics because any bad characteristics, such as those exhibited by spring tabs, will be shown up in the early stages in the form of high manœuvre loads, and pressure will be brought to bear from within the firm.

Under combat or emergency conditions, there can be little doubt that the pilot will pull, push or twist as hard as he can, if there is any chance of averting whatever misfortune awaits him. At the present time, if he does that the wings are likely to fall off. Possibly a more logical approach is to relate ultimate pilot effort to ultimate structural strength, and normal working effort to working strength. The snag is that the ratio of working to ultimate in the case of a man may be 4 to 1. That does not necessarily invalidate the argument, it simply means that the ultimate strength should be worked to for manœuvre loads. Associated with this approach, on the elevator, it might be necessary to use a g restrictor so that a reasonable stick force per g, say 30-50 lb. for bombers, could be retained without endangering the structure when forces of, say 300 lb. were applied rapidly to the stick. There has been some suggestion that g restrictors by themselves are sufficient safeguard. Possibly this is so for civil aircraft, but it is doubtful. On military machines rapid stick movements can be expected under certain circumstances, and thus large tail loads can arise before the g has built up, or the g restrictor come into operation.

This approach to the manœuvre load problem will be resented by some of the

simple spring feel exponents, but as their aircraft probably will have power-operated controls, the requirement can be met by arranging that a hydraulic blow-off valve, or electrical cut-out, restricts the maximum rod or jack load. The difficulty here is in calculating the hinge moment characteristics at high Mach number on the types of aircraft on which many people are experimenting. This is only one of the difficulties due to compressibility, mentioned earlier.

Another aspect of the manœuvre loads to be considered is that of what the aircraft is required to do, and what it may have done to it. Under normal flying conditions, a properly executed manœuvre is seldom a design case. It is the emergencies for which provision must be made. Correctly banked turns, and the control movements required to obtain them, steady sideslips and normal pull-outs, are usually harmless but evasive action, engine failure and exhibitionism, can have serious consequences. As pointed out earlier, these can only be catered for on a maximum effort basis.

Under the term emergencies, all manœuvres are included which, under present assumptions, bring some portion of the aircraft structure to its maximum permissible working stress. Clearly, the way in which these manœuvres are likely to be achieved must be considered. For elevators, there is a normal steady flight condition, followed by a rapid movement of the control column, resulting in a pitching manœuvre in which the design vertical acceleration for the speed considered is just reached. A similar elevator movement of opposite sign should then be applied, assuming an initial state of equilibrium of aerodynamic pitching moments at the design g. During each of these elevator movements, and the resulting response of the aircraft, the tail loads must be analysed for maximum positive and negative values, and the vertical and angular accelerations evaluated. This process should provide satisfactory data for logical stressing manœuvre cases.

The bone of contention is the rate and manner of application of elevator. The maximum likely rate must be used, and in some cases this is defined by the power control system. Where there is no mechanical limitation (remembering that an emergency is being considered) it is clear that the rate will depend upon pilot effort and upon the design excess g. Another factor which from experience may be taken into account in deciding the rate of control application is the stability and/or the response of the aircraft. The type of manœuvre described should be investigated at all the design speeds and under various Mach number conditions on high-speed aircraft. The calculations necessary at present are rather lengthy, and fairly involved. Much work is going on to reduce them and to obtain satisfactory approximations to the exact solutions. It is probable that before long there will be, at least in the military sphere, a revised set of pitching manœuvres in a form requiring an expenditure of effort merely appropriate to the extreme importance of the final answers. Critics should not allow themselves to be misled by the ridiculously small amount of labour required in the present inadequate cases. It is only by a proper investigation of the manœuvres and the parameters important to them, that design for low loads can be accomplished.

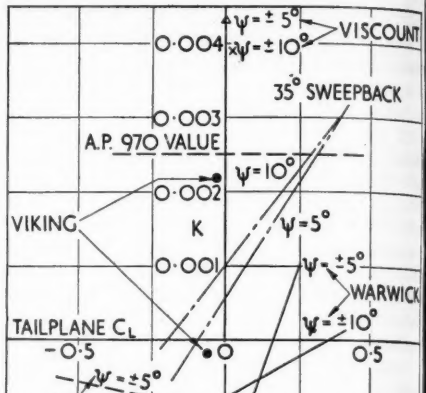


Fig. 8.
Tailplane rolling torque coefficient.

9.3. Assymmetric tailplane loading

Asymmetric tailplane loading during sideslips, with its resulting shear across the tailplane centre section, has been recognised as of considerable importance since 1943. The present requirements of A.P.970, based on the work of J.A.C. Sub-committee 27 are not completely satisfactory, as will be seen

from Fig. 8. It has been the practice in the author's firm to measure the asymmetric tail loading in the wind tunnel. The curves shown have been selected to show the wide variations which exist in the value of K, and it seems that there is no alternative but to continue with tunnel tests. The significant parameters include tailplane lift coefficient, dihedral, sweepback, tailplane-fin configuration, downwash, and so on. Levacic's work[4, 5, 6] may be of use in predicting changes due to sweepback, dihedral and plan form, but the fin blanketing effect is liable to reduce the practical value of the theoretical work when an attempt is made to apply it to tailplanes.

Another factor which has proved to be of importance in asymmetric tailplane loading, is tailplane buffeting at the stall. Failures have occurred recently as a result of this, and it seems as though the necessary strength has been provided quite fortuitously in the past. Modern configurations and design techniques seem to be making necessary a separate requirement to deal with the conditions. A requirement based on the maximum tailplane C_L and the difference in downwash which might occur between the two halves of the tailplane, might prove to be a satisfactory solution. Meantime, a careful watch should be kept on tailplane centre sections during stalling trials.

9.4. Fin and Rudder Loading

Some doubt has already been expressed about the validity and efficacy of the cases

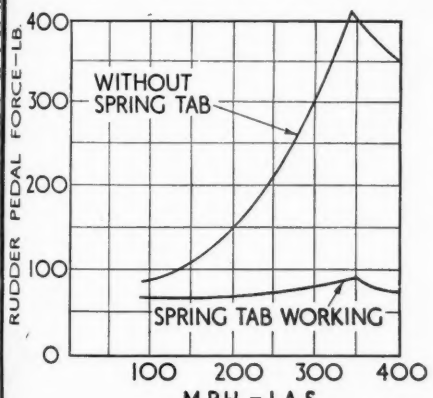


Fig. 9.
Rudder pedal force required to hold a windmilling engine. Power for level flight. Zero bank.

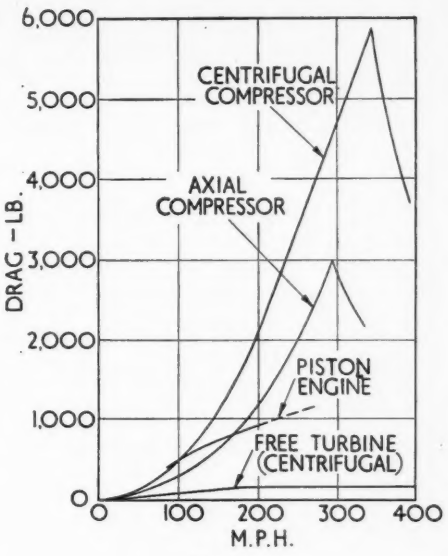


Fig. 10.
Dead engine drag against speed; airscrews at fine pitch stop.

which often design the fin and rudder and the fuselage in side bending. Possibly because of lack of data, the horizontal gust cases seem satisfactory at present. The manœuvres, if they may be so termed, are not. At the moment B.C.A.R.'s appear to be slightly more logical than A.P.970, although the position may soon be reversed. The present requirements involve respectively, several arbitrary configurations at V_A and equilibrium yawed flight obtained by unspecified methods at an angle of sideslip of $(0.7n_1 + 1{,}500/V_M)$ degrees.

The requirements certainly should differ in severity between military and civil aircraft; in fact, the rudder does little civil trade at all, but is kept for low-speed control and engine failure. On military aircraft it is required for certain types of violent evasive manœuvres. One which should be considered is that of applying the maximum normal foot force to the rudder pedal at combat speeds. Rapid, possibly instantaneous, rates of movements should be considered and an initial high fin and rudder load will occur, followed by a second peak load at the overswing position. This is particularly severe if the rudder is centralised during the response. Czaykowski[7] has investigated the aircraft response in this manœuvre, and reduced the solutions

to a simple form easily applicable for loading purposes. Incidentally, the approach used may be readily used in the case of yawing moments induced by engine failure, and so on.

Another manœuvre analysed by Czaykowski[8] which seems to be important for military aircraft, is a flat yawing manœuvre or "fishtail."

Investigations such as these bring forth some interesting results in aircraft with spring tabs on the rudder and also, aircraft with power operation and simple spring feel. It is the author's opinion that if stressing requirements do appear in such terms, then it will be impossible to obtain satisfactory control characteristics, coupled with low structure weight, unless other feel or balancing devices are employed. This is probably fundamental in the aerodynamic design of aircraft for high speed which must be capable of landing at relatively low speeds. Figs. 9 and 10 show the characteristics of the prototype Viscount rudder with and without spring tab and the drag which, at the time, was expected in the event of engine failure. The increasing efficiency of the spring tab with speed is obvious. At 100 m.p.h. the foot loads were reduced by 20 per cent., while at 350 m.p.h. the reduction was about 80 per cent. Thus the rudder was effectively very light at high speeds, with the spring tab working. On a civil aircraft this does not seem to be a danger, although it may point to the obsolescence of the civil requirements. On military types, such a characteristic would permit abnormally large fin and rudder loads to occur in evasive action. The basic remedy is the fitment of automatic feathering to the propellers, so that the large yawing moments due to engine failure at high speeds do not occur.

9.5. Auto-pilots

At this point, the question of auto-pilot loads can be considered with convenience. Many of the manœuvre load problems are reflected in those of the auto-pilot and *vice versa*. Logically, an auto-pilot when controlling an aircraft, should be able to fly the machine in rough weather and carry out manœuvres. (These manœuvres are becoming

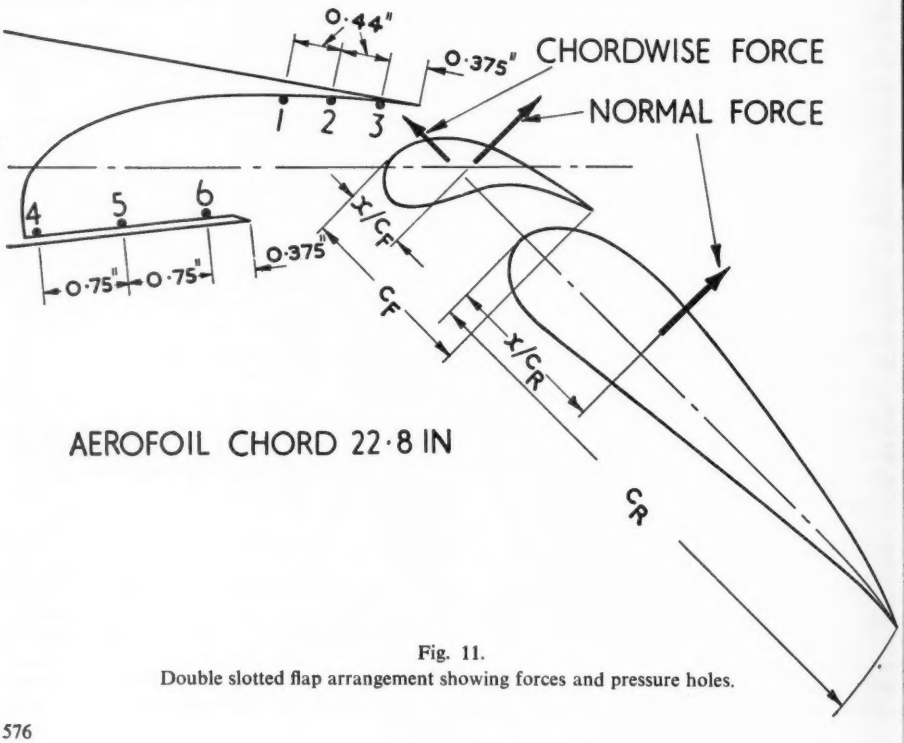


Fig. 11.
Double slotted flap arrangement showing forces and pressure holes.

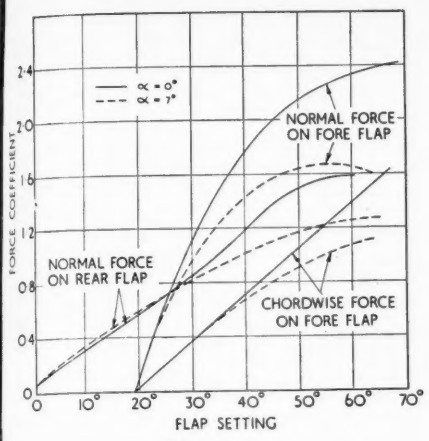


Fig. 12.

Force coefficients on Viscount double-slotted flap section.

progressively more complicated and the pilotless, but otherwise normal, aircraft is perhaps not far away.) In order to fly the machine in rough weather, the auto-pilot should be as strong as the man would need to be. Thus, it should be designed to suit the characteristics of the machine and the question of feel immediately arises. If the controls are light the auto-pilot should be reduced in power, otherwise a "runaway" could be catastrophic. The assumption of auto-pilot runaway is perhaps rather more drastic than the emergency action of a human pilot, which at least should be in the correct sense. As a man has great reserves of effort upon which to call, while the auto-pilot probably applies constant torque, man-made emergency action is likely to have more severe consequences than auto-pilot runaway if the auto-pilot has been correctly designed. At the present time, both military and civil authorities feel that maximum auto-pilot servo torque should be allowed for in the adverse sense to cater for failures. Thus, the principle of basing the design loads upon control feel is established.

It is only over the past year or so that real efforts have been made to get the auto-pilot in its proper form. There is no doubt that more logical design cases and more logical auto-pilots will be forthcoming, and that aircraft will be better and safer in consequence. Improvements will certainly result, because the effort is being made to treat the case rationally. The brains, the brawn and the experience have been brought together, and auto-pilots will soon exist which can do their job adequately without being sources of potential danger; structures will be able to cater for the forces required to fly the aeroplane and yet not be excessively strong.

Some interesting conclusions are reached when auto-pilot runaway is investigated. Firstly, and quite fortuitously, it will be found that rates of elevator runaway on contemporary aircraft fitted with the same Mark of auto-pilot, differ from 10 to 20 degrees per second. Obviously, the response, and relief due to response, on most aircraft will differ greatly. In its turn, the effect of runaway, particularly if fairly slow, will be conditioned by the b_1 as well as the b_2 of the elevator. As soon as the aircraft starts to respond, the effect of a large positive b_1 becomes important, because the stalling torque of the servo motor is reached rapidly and thus the severity of loading is diminished.

In general a safe requirement for auto-pilot failure is that runaway should be assumed in the adverse direction. If relief due to response is expected or claimed, calculations should be submitted to substantiate the claim. The question of the amount of "out-of-trim" to be allowed for when the failure is assumed to occur, is a vexed one and difficult to resolve, unless automatic trimming tabs are employed. The probability of dangerous out-of-trim being present if failure occurs is small, considering the relatively small trim changes which occur when an auto-pilot is set to control a given flight stage. Perhaps some warning to air crew, that it may be dangerous to fly on the auto-pilot when out of trim, would help.

9.6. Double-slotted flap loads

Double-slotted flaps have been singled out for discussion because, of the main types of flap, they are the type upon which there is available the least loading data, and also because they are becoming increasingly popular. From a structural viewpoint, this is understandable, even if the aerodynamic requirements of low drag—high C_L for take-off, low drag—higher C_L for approach and high drag and highest C_L for landing are forgotten; these should make them an automatic choice. The only real competitor in the high-lift field is the Fowler flap, and the main structural advantages which double-slotted flaps have over this are:—less falsework, deeper flap section for a given aerofoil and

thus stiffer and lighter structure, smaller aft travel and thus less structural and mechanical problems. This assumes the fixed-slot type of flap shown in Fig. 11, which is used on the Viscount series. The important loads on this flap, obtained by integrating pressure plottings, are shown in coefficient form in Fig. 12. The combination of the normal and chordwise forces on the fore flap can be seen to give a big "lift coefficient," probably bigger than would have been expected. Table II gives the centres of pressure of these forces obtained from the same integrations.

Another aspect which may be important structurally is that of the low-speed shroud loads. Table III shows the pressures measured at the holes, inside the shrouds, marked 1 to 6 on Fig. 11. These figures help to make good a deficiency in all the published data found so far; this has been concerned with the resultant forces, not the internal pressures.

9.7. Door loads

The main difficulty with estimating door loads is that two aircraft types seldom seem to have quite the same configuration, be it bomb doors, chassis door or camera door. Even if the doors themselves are similar some other feature, such as the chassis design, is so different that earlier figures are at best of doubtful value. The two most important aspects of door loading are the hinge moments and the distribution of load. In order to improve the firm's knowledge on the question of hinge moments, a systematic test is being carried out on various basic door configurations in the Vickers-Armstrongs wind tunnels. The test has no priority and is used as a "filler" in the 4 ft. tunnel when no more important tests are required. A considerable amount of data has already been obtained but no attempt has been made to draw conclusions from it yet, as there are still many more configurations to investigate.

TABLE II

FLAP CENTRE OF PRESSURE POSITIONS

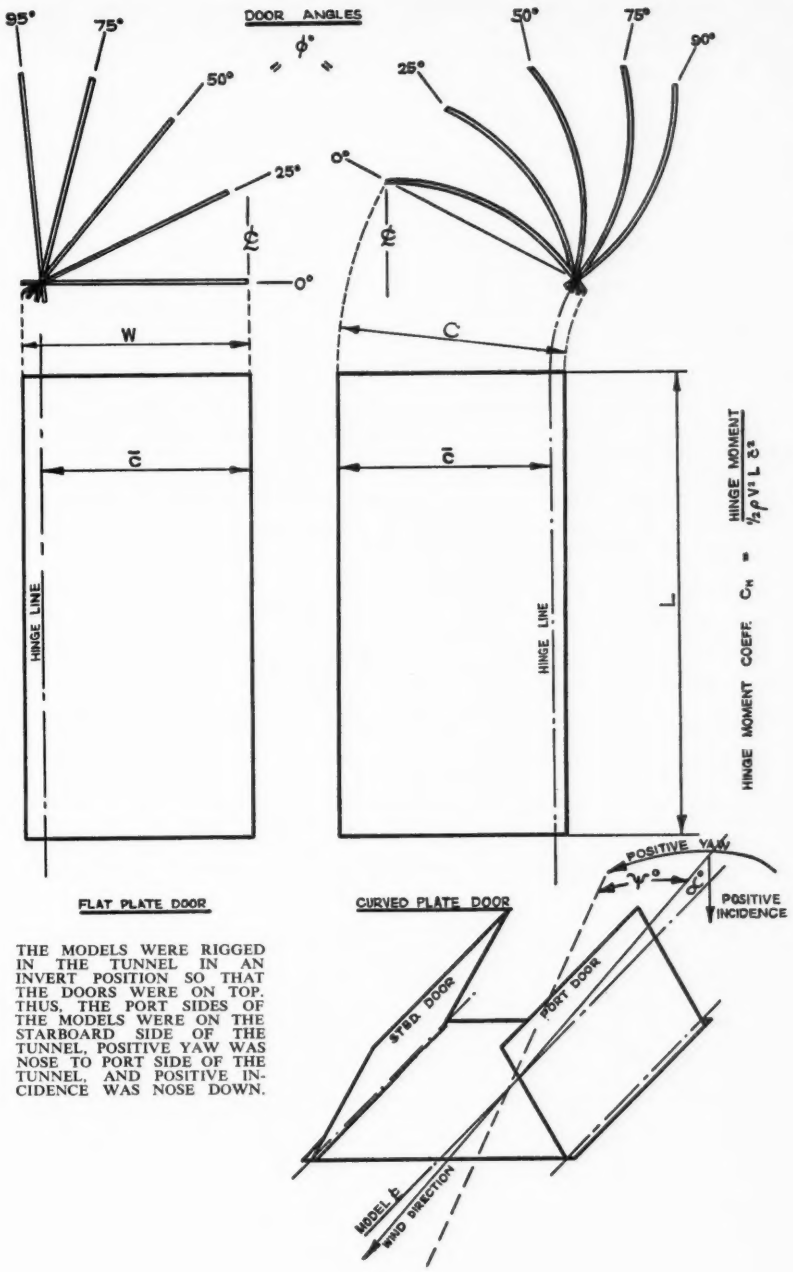
Flap Angle	*Rear Flap* Normal Force $-x/c_R$		*Fore Flap* Normal Force $-x/c_F$	
	$\alpha=0°$	$\alpha=7°$	$\alpha=0°$	$\alpha=7°$
0°	0.37	0.37	—	—
15°	0.34	0.36	—	—
45°	0.33	0.40	0.47	0.48
65°	0.44	0.43	0.40	0.41

TABLE III

PRESSURES INSIDE DOUBLE-SLOTTED FLAP SHROUDS

VALUES OF p/q

Incidence	*Flap Angle*	*Flap Position* 1	2	3	4	5	6
0°	0°	−0.126	−0.116	−0.122	−0.119	−0.122	−0.123
0°	20°	−0.115	−0.172	−0.328	−0.091	−0.093	−0.120
0°	35°	+0.355	+0.183	−1.41	+0.242	+0.215	+0.211
0°	40°	0.402	0.606	−0.027	0.305	0.285	0.285
0°	45°	0.325	0.610	+0.457	0.315	0.275	0.267
0°	50°	0.379	0.617	0.511	0.371	0.342	0.328
0°	60°	0.626	0.735	0.669	0.523	0.484	0.476
6°	0°	−0.135	−0.127	−0.133	−0.130	−0.131	−0.132
6°	20°	−0.158	−0.203	−0.330	−0.138	−0.140	−0.186
6°	35°	+0.375	+0.211	−1.35	+0.233	+0.205	+0.194
6°	40°	0.441	0.659	+0.049	0.327	0.297	0.303
6°	45°	0.350	0.650	0.483	0.330	0.290	0.293
6°	50°	0.388	0.685	0.553	0.366	0.337	0.335
6°	60°	0.621	0.782	0.757	0.538	0.499	0.492



THE MODELS WERE RIGGED IN THE TUNNEL IN AN INVERT POSITION SO THAT THE DOORS WERE ON TOP. THUS, THE PORT SIDES OF THE MODELS WERE ON THE STARBOARD SIDE OF THE TUNNEL, POSITIVE YAW WAS NOSE TO PORT SIDE OF THE TUNNEL, AND POSITIVE INCIDENCE WAS NOSE DOWN.

Fig. 13.
Chassis door research—notation.

The effects which are being examined in the first series of tests are those of hinge line inclination to flight path, door aspect ratio, position of door relative to nose of body, and difference between curved and flat doors. It is hoped to arrange further tests covering the effect of chassis blockage. The hinge moments are measured by a mechanical balance for a range of angles of sideslip and door opening.

Figures 13-16 show the test arrangements and some typical results; Fig. 17 shows an interesting modification for comparative purposes. It is hoped that when these tests are complete it will be possible to avoid the necessity of doing tests on particular models, except in special circumstances.

The other problem is to decide the stressing conditions to be assumed. For doors connected with take-off and landing, the conditions assumed should cover unbanked flight with an engine failed, take-off and landing in a cross wind and side gusts. It is necessary also to differentiate between stressing loads and operating loads, because in a side gust, for example, the fact that the doors temporarily stopped opening might not matter, but failure of their structure certainly would.

For bomb doors, camera doors, and so on, which would be open at high speed, the yawing manœuvres described earlier should be considered. Arbitrary angles of sideslip have but little merit and even if used on the score of simplicity, there seems no good reason why the arbitrary angle of A.P.970 Chapt. 202 of "$(400/V_M)\times 15°$" should differ from the "$0.7n_1+1{,}500/V_M$" of Chapt. 206.

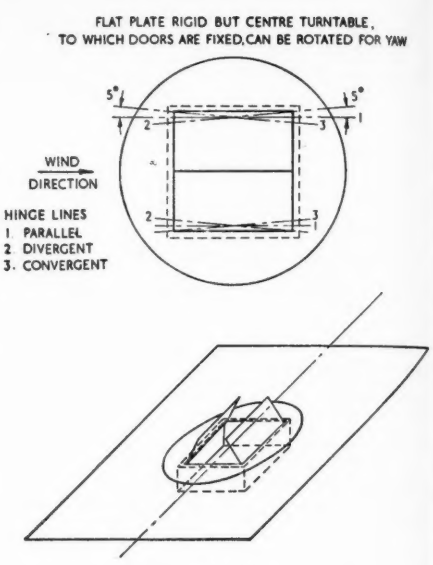

FLAT PLATE RIGID BUT CENTRE TURNTABLE, TO WHICH DOORS ARE FIXED, CAN BE ROTATED FOR YAW
WIND DIRECTION
HINGE LINES
1. PARALLEL
2. DIVERGENT
3. CONVERGENT

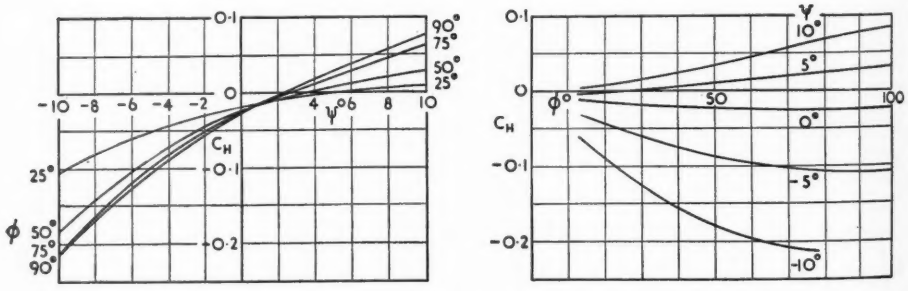
Fig. 14.
Chassis door research.
Model used for flat plate doors on a plane surface.

It should not be more severe on bomb door than on fin and rudder.

In addition to the manœuvres, gust cases and engine failure should be examined as a matter of course.

9.8. Pressure distributions

It is easy to waste an unnecessary amount of wind tunnel time on measuring pressure distributions, although the results themselves



L = 2W α = 1°

Fig. 15.
Chassis door research.
Hinge moments for flat plate doors on a plane surface—hinge lines parallel.

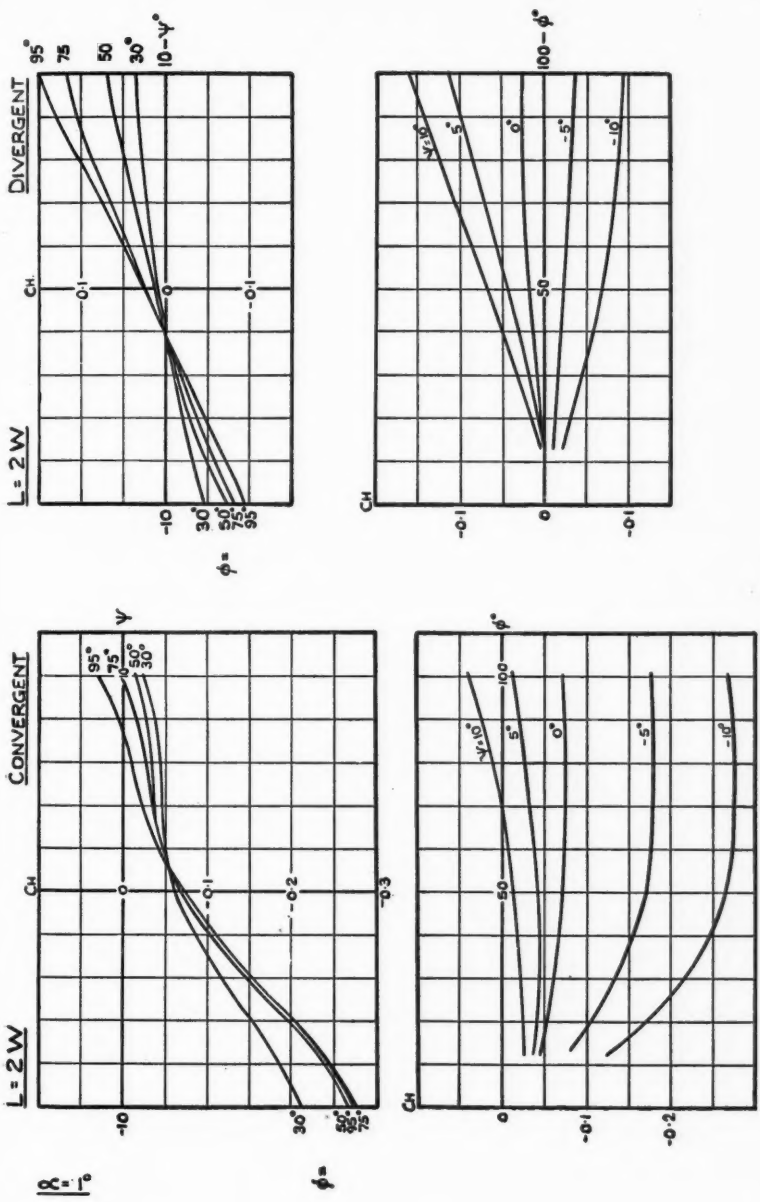


Fig. 16.
Chassis door research.
Hinge moments for flat plate doors on a plane surface—hinge lines at 5° to centre line.

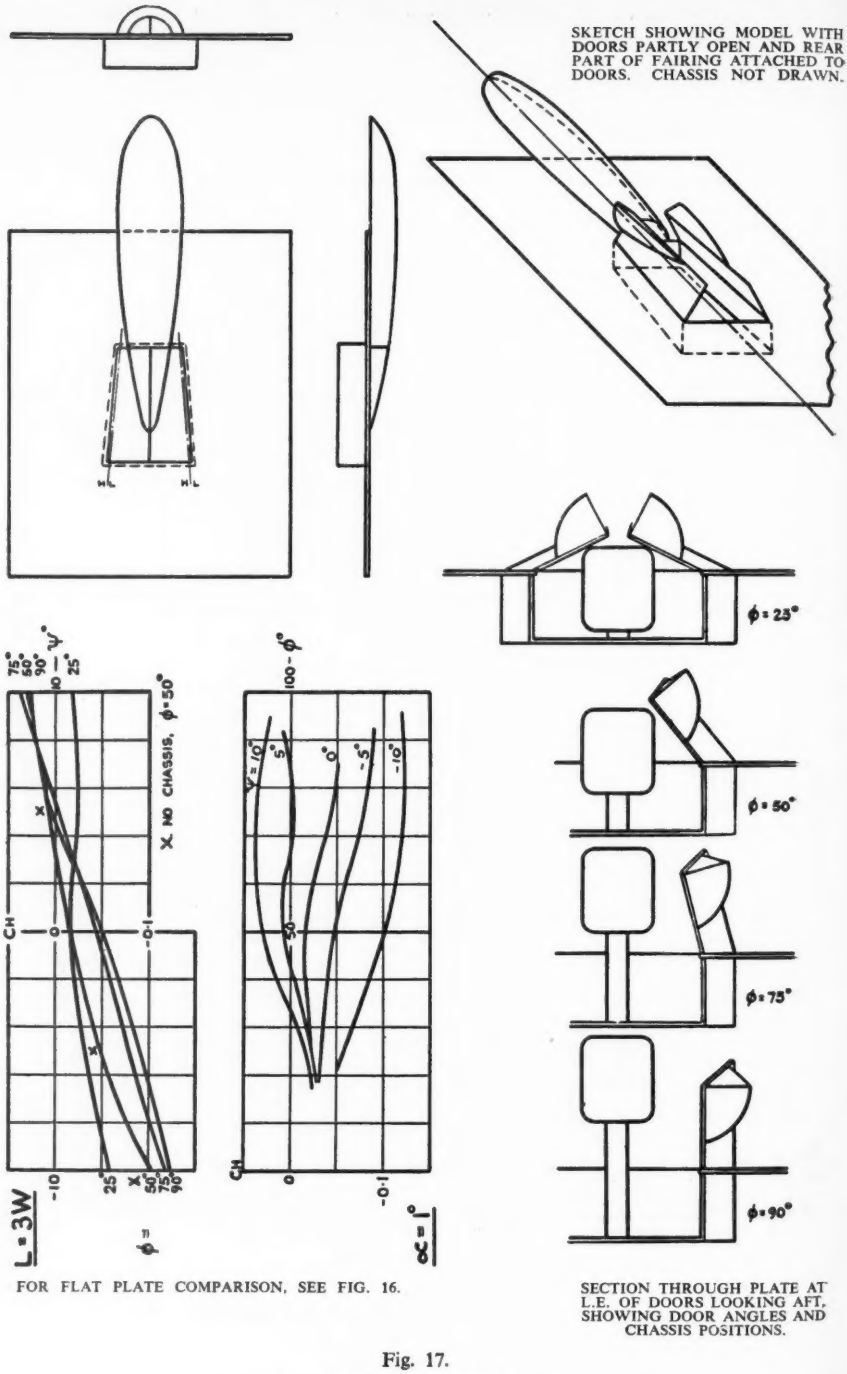


Fig. 17.

Chassis door research.

Hinge moments for flat plate doors on a plane surface with a nacelle fairing attached to the doors—hinge lines at 5° to centre line.

are usually good if they are obtained carefully.

Much of the time wasting occurs through rigging a model for pressure measurements on a small region and then removing it, only to replace it again a few weeks later for tests on another small region. It is a good plan to cover the entire fuselage in one pressure plotting test because there are always calls for static vent positions, waste exits, cooling air exits, and so on, in addition to the queries about loads. Strictly from the loading aspect, pressure measurements at low speed could be confined to wing fillets, cabin tops, and so on, which may have high peak suctions, and windscreens and parts of the fuselage, nacelles, and so on, which are fitted with doors. Wing pressure distributions seem to be satisfactorily calculable. Those parts of a normal fuselage which have no doors or local weaknesses should not be susceptible to the magnitude of pressure which they normally encounter, except perhaps for the fuselage in the region of the wing peak pressure. Many of the troubles encountered arise not from external pressures, but from leaks which cause unexpected differential pressures over the critical region. Where there is any doubt about the internal pressure in a certain region it is much safer to vent the compartment to a known static pressure than to assume that the internal conditions are ambient atmospheric. This venting is a practice which must be used with caution, because it may lead to losses of performance if there are other leaks which enable air to flow into the airframe and out through the vent.

High-speed pressure distributions are a separate problem. The shock wave effects on shrouds are touched on in Fig. 5, and in addition there can be similar distributions causing large loads on flaps when raised, and so on. In fact, it is not uncommon for more severe flap stressing cases to occur with flaps up at high speed than with flaps down at low speed. There are several useful reports available to the Industry which show recent pressure measurements on thin aerofoils suitable for use in such cases. It is preferable to use these and the pressure rises they give through the shock waves than to rely on estimates based on rather unsatisfactory assumptions. There does not seem much prospect in the near future of high-speed tunnel pressure plottings being available "to order" because the available tunnels in Great Britain are engaged on more important measurements.

On the less advanced looking types of aircraft which still exhibit engine nacelles, it is a most unpleasant task to try to allocate to a wing structure the ΔC_{m_0} and shift of aerodynamic centre due to a nacelle. The overall shift of aerodynamic centre must mean a much larger sectional shift in the region of the nacelle, and this can be important. In the absence of local pressure plottings, a commonsense arbitrary distribution of load should be made in the light of the measured or estimated increments. The effect should most certainly not be ignored in summing up the wing torsion. If it is, it will prove impossible to balance out the wing and fuselage pitching moments—not that this is always achieved.

During the flight test stage, air-to-air photographs from all angles can be informative. Through this medium it has been possible to trace poor performance and high Mach number troubles, such as buffeting, to doors partially opening in flight, and to excessive billowing on regions with thin gauge skin. Both these effects result from inadequate allowance being made for differential pressures.

Spanwise load grading is important on modern designs, particularly those with sweepback, and it is necessary to make careful investigations with due allowance for distortion. The work of V. M. Falkner, published when he was at the National Physical Laboratory, has gone a long way towards improving the technique of load grading and providing solutions of practical, rather than academic, interest.

Careful estimation of load grading is essential if the present thin wing structures are to be designed with the minimum possible reserve factors and yet be flown with the maximum confidence.

9.9. Controls

Loads on controls themselves are fairly easy to estimate, at least at low speeds. The difficulty lies in finding the configuration which gives the design load. The important loads are the hinge moments and the hinge normal forces. Ignoring temporarily the spanwise distribution of hinge moment, the condition which must be investigated is obviously that which combines the maximum product of control angle and E.A.S. Until recently most elevators and rudders were

stressed to arbitrary chordwise loadings obtained from an Appendix to A.P.970; the actual control angles and angle of attack of the primary surface were ignored. This does not seem logical, although it appears to have been at least adequate. On the other hand, ailerons have probably been stressed much more logically because the manœuvres in which they are to be used are defined, and most people will have allowed for the effects of b_1, b_2, etc., in their investigation. As soon as logical elevator and rudder manœuvres are included in the civil and military stressing requirements, it will be possible to define the appropriate control stressing cases accurately.

The advent of power-operated controls has made the spanwise hinge moment distributions much more significant because it has become possible now to fly at higher speeds with large tab deflections, without inconvenience. The tabs may be at large angles as a result of failure, or because of carelessness on the part of the pilot. How they may get to the position is immaterial; what must be allowed for is the loads which will be imposed. "Progress" is leading towards thin trailing edges and all kinds of automatic and mechanical trimming devices. It must be ensured that the appropriate stressing conditions are investigated in each case.

The ultimate factor of 1.5 specified in most normal cases is also under suspicion where power controls are concerned. The reason is that if safety of control rods, and so on, is ensured by the use of a force limiting device, such as a "blow off" valve in the hydraulic system, it is more likely that the maximum load will be reached frequently. This is particularly so where the loads which the pilot has to overcome are small. The factor of 1.5 was not intended to cover fatigue when the maximum load was reached frequently. A factor of 2.0 or more is necessary in these circumstances, depending upon the severity of the case.

Distortion is another aspect in which the aileron requirements are ahead of those for elevators and rudders. It is paradoxical that the most important flying control, the elevator, should be ignored completely in the requirements and yet the ailerons should be given a treatment so thorough that allowance for aeroelastic distortion has been made since 1942.

Compressibility effects, particularly when shock waves occur, must be taken into account on controls, particularly if they are not manually operated. If they are manually operated, there is a good chance that significant shock wave effects will be communicated to the pilot in such a way that he reduces speed before serious trouble occurs or the machine gets out of control, in which case it is difficult to apply rational requirements. With power-operated controls there is a good chance of getting severe stressing conditions due to shock waves. These must be catered for and an investigation of the high-speed tunnel data on aerofoils with controls deflected, mentioned previously, can yield some interesting figures.

9.10. Design for low aerodynamic loads

It is essential for future aircraft that much more attention than hitherto, should be paid to the subject of careful *aerodynamic* design for low structure weight. All too often in the past, bright new aerodynamic schemes have been decided without sufficient thought to the structural penalties. Often, careless and thoughtless decisions have been made, and accepted, which have resulted in large loads unjustifiable by the aerodynamic gain. An obvious example of this, as previously mentioned, is the choice of an unnecessarily highly cambered wing section with its attendant large C_{m_0} and tail loads.

On the aircraft which are in the embryo stage now, one of the greatest difficulties is that of aeroelastic distortion. Much of the possible structural relief, and thus the ultimate success of the designs, lies in intelligent side-stepping of the aeroelastic problems. Among the useful devices which may be employed are spoilers and the trimming tailplane. These will be considered separately.

9.11. Spoilers

The use of spoilers for lateral control appears to be one of the major changes of configuration which may come up for structural consideration fairly soon. The difficulties of providing satisfactory low speed characteristics may be overcome or side-stepped, on experimental aircraft at least, by producing one or two really long runways and allowing the aircraft to touch down at speeds around 200 knots.

When spoilers do come into use, there can be little doubt that the structural penalties of good lateral control will be much reduced.

The major gain will come from the reduced wing torsional stiffness which may be permissible if the spoilers are fitted so that when in use they cause no wing twist, or possibly even a favourable one. Attention must be paid to the flutter side but there is a good prospect here that, with careful design, the severity of the stressing conditions can be materially reduced.

9.12. Trimming tailplanes

The trimming tailplane, which in this discussion is assumed to be one which provides all the necessary longitudinal control without the need for an elevator, is another stage in conventional (*i.e.* non-tailless) aircraft development which may be readily foreseen. For many years variable incidence tailplanes have been used, with conventional elevators, for large changes of trim such as occur due to ground effect on downwash when landing. At high speed, satisfactory elevator effectiveness depends to a large extent on the elevator reversal speed which, in its turn, is dependent upon the shift of the tailplane c.p. relative to the tailplane torsional axis when the elevator is moved. If changes of trim and manœuvres can be looked after, without the use of elevators, by movement of the tailplane, then the c.p. of the tailplane (in this case it is the aerodynamic centre) remains in the same place. If the torsional axis can be made roughly coincident with this, then one of the main contributions to aeroelastic elevator ineffectiveness is eliminated, with a result that it should be possible to work to a lower torsional stiffness criterion for a given loss of "elevator" power than if actual elevators were used. On a conventional torsion box structure, this will mean a considerable reduction in the skin gauge required, with a consequent weight saving. An aerodynamic advantage is also present because loss of tailplane effectiveness due to compressibility is likely to be less marked than loss of elevator effectiveness.

10. CONCLUSIONS

It may be felt that criticism has been unduly harsh of some of the old stressing cases and methods which have served us well and faithfully. The author is aware that they have been successful and can only hope that the changes foreseen will prove of equally sound foundation. The intolerance expressed is not for the answers the cases gave, but for the empirical nature of the cases, which has almost certainly retarded progress towards lighter structure by failing to encourage intelligent investigation.

Progress is forcing a change in attitude to aerodynamic loading, just as it has forced a change in the attitude to compressibility. Designers have had to learn rapidly how to avoid bad compressibility effects, and must learn also how to design for low aerodynamic loads. When this is learnt then all aerodynamic loads will be estimated by aerodynamicists who are conversant with what is going on in all parts of the aerodynamics department. Close liaison with the flight testing section will be essential. Some firms are already well on the way to such an arrangement; others must be guided towards it. When this has been achieved, and it must be soon, another important milestone will have been passed on the road towards the optimum aircraft for a given operational role. The achievement of this is an aircraft designer's job. He should need no other incentive.

ACKNOWLEDGMENTS

The author would like to thank the Royal Aeronautical Society for the opportunity to present this paper and Vickers-Armstrongs Ltd., Weybridge, for permission to do so, and to use the data on the chassis door research and the flap loads. He is grateful also for the advice, help and information which he has received from various members of the Technical Office staff at Weybridge. The opinions expressed in the paper are entirely the author's responsibility.

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NOSE-WHEEL STEERING SYSTEMS

by

H. G. CONWAY, F.R.Ae.S.

SUMMARY

These notes are intended to summarise for the benefit of aeronautical students the basic requirements of nose-wheel steering hydraulic systems. The various factors which have to be considered are listed and representative solutions given.

1. INTRODUCTION

Nose-wheel steering systems are specified on most modern aircraft to

(*a*) facilitate directional control during the early part of the take-off run;
(*b*) facilitate rapid taxy-ing and close parking;
(*c*) eliminate the overheating of brakes which occurs when differentially braking for steering purposes.

2. DIRECT STEERING SYSTEMS

On light aircraft (up to about 3,000 lb.) direct connection of the rudder bar to the nose wheel (even in flight) may be practicable and has been used successfully.

Direct steering has been used on larger aircraft in special cases but the angle will be limited (*e.g.* $\pm$ 5° on the Marathon of 15,000 lb. all-up weight). In this case the connection should be uncoupled by retraction.

3. POWER SYSTEMS

Power steering is normally required on other types of aircraft. The system will consist basically of

(*a*) steering jack or jacks on the nose-wheel unit;
(*b*) a power supply, usually with accumulator;
(*c*) a pilot-operated steering wheel or lever;
(*d*) a control valve;
(*e*) a mechanical follow-up linkage joining the control valve to the nose-wheel unit, and the pilot's control;
(*f*) a differential lever mechanism or equivalent.

Paper received May 1951.

Mr. Conway is Technical Director of British Messier Ltd.

4. SPECIAL REQUIREMENTS

Some or all of the following additional special requirements have to be considered and dealt with:

(*a*) shimmy damping;
(*b*) disconnection of the system during and after retraction;
(*c*) centring of the undercarriage;
(*d*) isolation of pilot's control in the air;
(*e*) a residual amount of steering power when the hydraulic system is out of order or not working (or when parked);
(*f*) deliberate selection of steering power-on by the pilot;
(*g*) maximum safe steering rate;
(*h*) variable velocity ratios to increase central sensitivity;
(*i*) free castoring with steering off, or when control is released, and particularly at touch down or for a cross-wind landing;
(*j*) provision for landing with one tyre of a pair burst.

5. DESCRIPTION OF COMPONENTS

5.1. STEERING JACKS

The steering jack or jacks will be of normal construction except in so far as their attachment to the leg may complicate design. The power of the jack depends on requirements but will be approximately of sufficient power to skid the nose tyres on a ground surface of coefficient of friction of 0.5 (*i.e.* $\mu=0.5$), allowance being made for average rotational friction in the leg bearings (*e.g.* bearing $\mu=0.1$).

An important requirement (paramount when the jacks deal with shimmy damping) is

the minimising of backlash and deflections between the wheels and the steering jack. This means that the mounting of the jack in the airframe (although facilitating the mechanical connection of the follow-up system) is not as satisfactory as on the leg itself.

Steering angles greater than $\pm 50°$ are not easy with simple jack mountings. The multiplying linkage of Fig. 1 can be used to increase steering angles up to even $\pm 90°$. The "non-linearity" of such a linkage is usually not inconvenient.

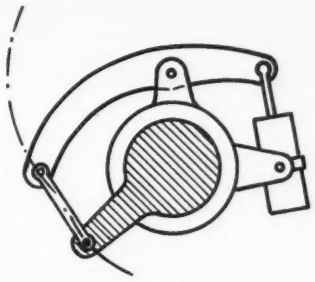

Fig. 1.

5.2 POWER SUPPLY

The power supply circuit is likely to be of the type shown in Fig. 2.

The supply for the main system is taken through a non-return valve to an accumulator, giving a stored volume for steering with the main system inoperative. A cock (preferably electrically controlled) enables the

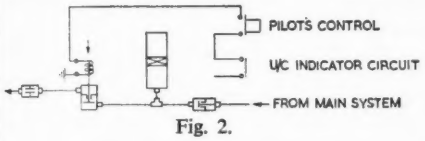

Fig. 2.

steering system to be isolated except when deliberately required, or when the nose (or main) undercarriage is fully lowered.

A restrictor to control the maximum steering rate may be required (*see* Section 6.7).

5.3. PILOT'S CONTROL

The pilot's control may be by hand or foot. Hand control is known in three forms:—

(*a*) a small steering wheel, usually on the left of the first pilot or on his right where it is accessible to the second pilot;

(*b*) a rotating lever;

(*c*) a concentric wheel inside the aileron wheel.

The hand wheel control may require as much as two turns, although preferably about $\pm 75°$ so that the pilot can obtain a wide range of control with one hand without moving his grip. A rotating lever or concentric aileron wheel (neither of which is recommended) will require much smaller angles. The switch for the electric cock in the power system may be on the aileron wheel (*i.e.* controlled by the pilot's other hand) or by hinging the steering wheel, or by slight free travel on rotating it; the first is preferred.

Foot control is by the rudder bar or pedals, and introduces special problems of its own. It has the advantage of leaving both hands free for control column duties. On the other hand most or all of the steering linkage should be uncoupled in flight to avoid friction loads on the rudder pedal; in addition, the nose wheel and rudder bar may not be in phase when steering is switched on, and must not re-phase without pilot's action.

Figure 3 illustrates a disconnection mechanism for rudder bar control.

The clutch is engaged by switching on steering power pressure. The clutch will not jam if engaged out of phase but will engage

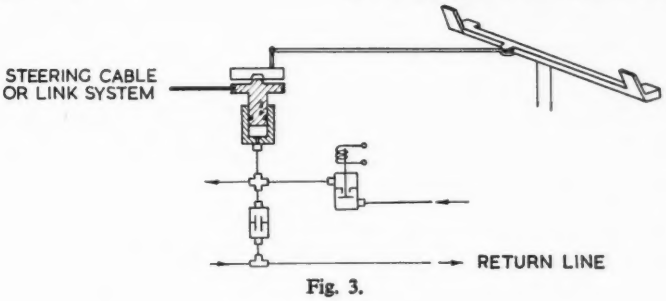

Fig. 3.

when the rudder bar is phased with the nose-wheel. When switched off, the clutch releases hydraulically through a permanent leak, or by using a three-way selector in place of a cock.

5.4. Control valve

The control valve does not have to be completely leak proof (since invariably there is a surplus of steering hydraulic power) but should be opened fully with a small travel. Slide valves are most suitable. The valve should be self-centring by means of a spring assembly to prevent inadvertent steering and to enable the steering linkage to reverse freely when the wheel is castoring (in this case the linkage friction must be less than the control valve centring force). To enable the steering jack to pass oil back and forward when castoring freely, the selector must be of the centre-vented type (*i.e.* inlet closed, all other connections connected in the neutral position). Fig. 4 shows a typical control valve diagrammatically.

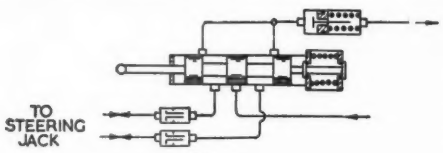

Fig. 4.

Steering sensitivity is proportional to the angular movement of the nose wheel corresponding to valve overlap and travel. Overlap will be of the order of 0.008 in.; for normal steering rates, a valve opening of 0.010 in. will pass full required flow, making the valve motion from central to fully open, $0.010+0.008/2=0.014$ in., say ± 0.02 in. Assuming a valve linkage motion on the steering wheel or nose wheel end of ± 2 in. minimum, the motion of the valve due to the differential linkage (*see* Section 5.6) will therefore be ± 1 in. This implies using usefully only ± 0.02 in. out of ± 1 in. motion or, in terms of valve overlap only, ± 0.004 in. in ± 1 in.

The corresponding sensitivities are thus one in 50 or one in 250 respectively. However, the design of the valve is much complicated by requiring so much over-travel, and unless special mechanisms are used (*see* Section 5.6) valve travel will have to be reduced to, say $\frac{1}{4}$ in., causing a loss in sensitivity and inconveniently short linkage motions.

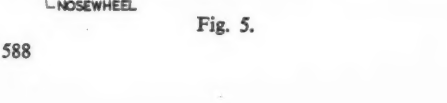

Fig. 5.

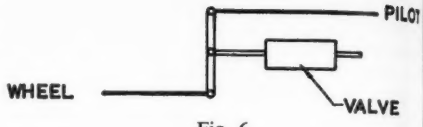

Fig. 6.

5.5. Follow-up linkage

The mechanical linkage from pilot to nose wheel, broken at the control valve, is fundamental, but one part of it may be kept short by mounting the control valve close to the pilot's control, or on the nose wheel itself.

Provision must be made for retraction of the nose wheel without adverse effect on the linkage.

The choice of linkage will depend on the travel involved. A short lever length on the nose wheel is unlikely, as is a linkage or cable motion of less than 2 in. In place of normal linkage or cable runs, the system shown in Fig. 5 may be useful, although it will probably involve an excessive number of pulleys.

In this system the valve motion is caused by a difference in tension in the two parts of the cable resulting from a de-phasing of the pilot's control and the nose wheel. With rudder-bar steering provision must be made for complete de-phasing (*e.g.* rudder bar full right, wheel full left) and load limiting devices in the cables or rods are probably necessary to avoid using cables capable of taking full foot loads.

5.6. Differential lever mechanism

The basic mechanism of any hydraulic servo is shown in Fig. 6; the valve motion is half that of the control linkage. Practical designs use equivalent mechanisms. These include gear and screw systems.

Figure 7 shows a bevel differential. Fig. 8 shows an equivalent spur gear differential,

Fig. 7.

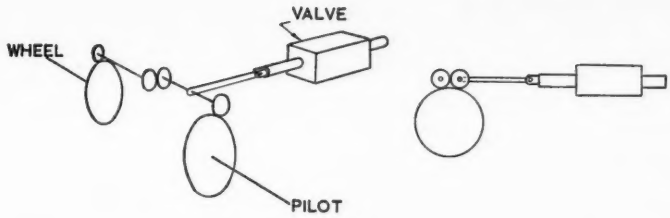

Fig. 8.

Fig. 9 an epicyclic differential. A screw differential mechanism is illustrated in Fig. 10.

Figures 7, 8 and 9 are reversible; Fig. 10 is not and will require an extra centring spring assembly to allow the valve to centre if it is released in a position away from neutral.

All these mechanisms are kinematic equivalents of the differential lever, the valve motion being linearly proportional to the linkage motion (*see* Fig. 11, curve A). In order to increase sensitivity by opening the

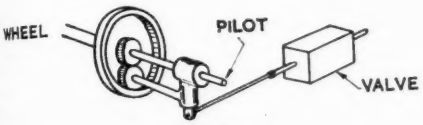

Fig. 9.

valve rapidly what is wanted is a curve as at B in Fig. 11 where the valve over-travel is avoided. This can be achieved by a mechanism equivalent kinematically to that of Fig. 12.

In this case also, external centring must be used on the differential mechanism.

6. DISCUSSION OF SPECIAL REQUIREMENTS

6.1. SHIMMY DAMPING

Shimmy damping is vital: suitable means of achieving it include

(*a*) coupled or co-rotating twin wheels;
(*b*) use of a twin-contact tyre;
(*c*) hydraulic damping;
(*d*) friction damping.

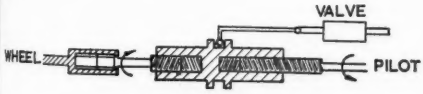

Fig. 10.

Systems (*a*), (*b*) and (*d*) involve an increase in nose-wheel steering torque, but not more than about 50 per cent. in the most adverse arrangement; the steering system is otherwise unaffected.

Hydraulic damping, as at (*c*), can be achieved by restricting the flow of oil from the steering jack volumes. Fig. 4 illustrates the location of appropriate restrictor valves and means for ensuring that the jacks are full of oil with a low pressure accumulator-relief valve. The displacement of jack volumes should be equal during motion.

6.2. DISCONNECTION

The steering system must be disconnected or isolated during and after retraction. This can be done by

(*a*) mechanical disconnection of the steering jack during retraction. Fig. 13 shows a known method.
This is usually only convenient with a leg where the jack steering jack is mounted on the aircraft, which is not recommended practice. An equivalent and more convenient system is to allow cables to become slack on retraction;

(*b*) electrical isolation of the steering engaging control valve, through a micro-switch (*e.g.* the landing gear retraction indicator switch);

(*c*) a mechanically-operated valve (*i.e.* a type of sequence valve) which opens only when the leg is down to admit oil

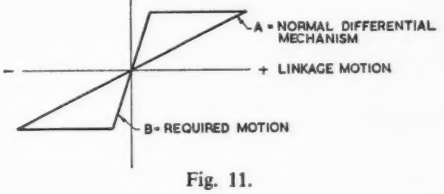

Fig. 11.

pressure to the steering system and thus closes during retraction;

(*d*) a powerful centring device (*see* Section 6.3).

6.3. Centring

The nose leg must be centred by any one of several known systems; one method makes use of centring cams engaged by the extension of the oleo at take-off, and this can often be arranged to be more powerful than the steering system to prevent steering in flight. Reliance on this method alone is not recommended, however, owing to the high forces set up when trying to steer, but the system is a good one used together with electrical isolation.

6.4. Isolation of the Pilot's Control

With hand steering it is sufficient to lock the nose wheel, the steering wheel then either being locked by the mechanical linkage to the

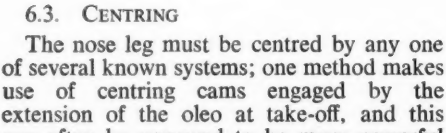

Fig. 12.

leg, or free to move against a centring spring, without doing any harm.

With foot steering, the rudder bar must be disconnected in flight (*see* Section 5.3).

6.5. Residual Steering Power

An accumulator in the steering power system (Fig. 2) can be used to store energy for steering with the engine-driven pumps not operating.

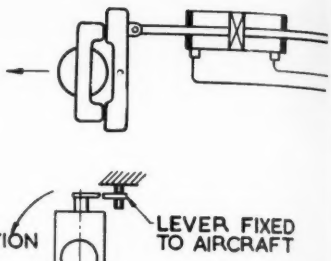

Fig. 13.

6.6. Deliberate Selection of Steering

Deliberate selection of steering by pressing a switch is a desirable feature (*see* Section 5.3).

6.7. Maximum Safe Steering Rate

It is important (particularly with rudder-bar control) to ensure that the maximum rate of steering does not lead to rates of change of direction of the aircraft which would critically load the nose wheel or aircraft. Comparatively slow maximum rates (5° to 10° of nose-wheel turn per second) will be found adequate in most cases.

A simple restriction of input flow (*see* Fig. 2) is a good means of achieving the desired control. It is important also to realise that the steering valves can usually be quite small.

6.8. Variable Velocity Ratio

For a given steering wheel or lever angular movement, the introduction of a variable velocity ratio in the linkage system will

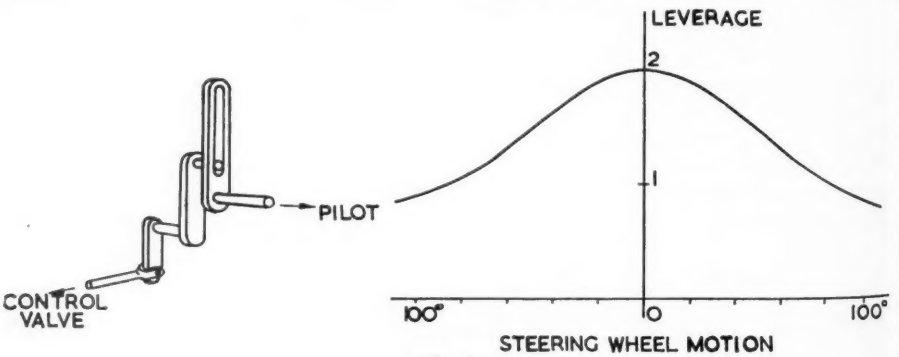

Fig. 14.

enable a low gear ratio to be used centrally for maximum sensitivity at this point, with a higher ratio at the extreme positions which are used only during taxy-ing.

Figure 14 illustrates diagrammatically a kinematic solution.

6.9. Free castoring at touch-down

The wheels must be free to move rapidly into the line of motion when landing with yaw, and to castor freely when manœuvring without steering. This means

(*a*) that the steering system must be fully reversible, or

(*b*) that the jack connections are short-circuited when the steering control valve is neutral.

It can be assumed that the pilot will not land deliberately with steering on and the wheel deflected. To expect the steering system to reverse rapidly may be too much, especially if the linkage is long and of appreciable inertia. It is not difficult to arrange the steering selector to be of the "centre-vented" type, as shown in Fig. 4.

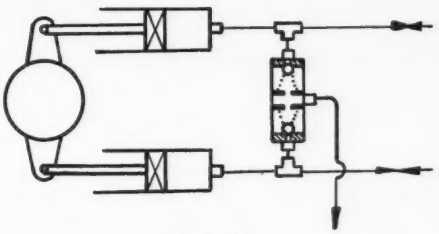

Fig. 15.

6.10. Landing with one tyre burst

If one tyre of a pair bursts at touch-down, the other will slew round several degrees and continue to run much yawed, the offset couple being resisted by a twisting force at the ground from the yawed tyre. (If the coefficient of friction on the ground is low, as on grass, the wheel may indeed turn right round and the good tyre be ripped off.)

In order to limit the pressure in one of the steering jacks during such a landing, relief valves should be used, as shown in Fig. 15. As these will operate very rarely, they can exhaust to the atmosphere; they should be mounted as close to the steering jacks as possible.

REVIEWS

THE JUBILEE BOOK OF THE NATIONAL PHYSICAL LABORATORY. H.M.S.O. 1951. 104 pp. 32 illustrations. 4s. net.

By a happy chance, the jubilee of the foremost government research establishment occurs in the centenary year of the Great Exhibition which itself formally proclaimed this country's future pre-occupation with all things scientific. All jubilees should leave behind them their mementoes, and it is right that a book should be published at this time describing the achievements of the National Physical Laboratory during its first fifty years of life.

But the question is: what sort of book? Is it to be for the enlightenment and interest of the scientist, or for the information of the man in the street who is interested but relatively ignorant? Compromise there cannot be, between these two possibilities, for it will annoy equally both classes of reader. The answer in this case must be that an event which is of the utmost interest both to the community as a whole and to a highly specialised section of it should be recorded and described in two quite different ways. The proposition that $1+1=2$ receives a treatment in *Principia Mathematica* which differs slightly from that in a child's arithmetic book.

The book under review, let it be quite clear, is intended for the man in the street, the man to whom science is on the whole a mystery, and whose mind is impervious to any detailed information. John Langdon-Davies is expert at describing things in such a way that the ordinary man is drugged into thinking he understands what he is reading: and there is no doubt that he has done a good job of work here. Scattered throughout the book are values of lengths, times, masses and of many combinations of these three basic dimensions with at least six significant figures in them which apparently give the reader every right to think how wonderful metrological science is. And so it is wonderful to be able to measure things to an accuracy of one in a million and one of the best things in the book is the description, in the first three pages, of why it is so important to go on chasing the next decimal place.

Just as the nuclear physicist becomes very wary when he talks of the existence of α-particles except in terms of observations, so the metrologist takes some trouble to explain to what extent the performance and characteristics of his measuring instruments are inherent features of the definitions he is attempting to formulate. It is a pity that the author of this booklet has not at least mentioned the philosophic questions of measurement, for there will be many laymen who can perceive, if only darkly, some of the difficulties.

But this is an entertaining book and interesting, and if it does not hang together particularly well, that is mainly the fault of the enormous diversity of the N.P.L.'s work. It will not endure, however (if only because it has only soft covers). The Government should shoulder its full responsibility and produce another book—dare one say a scholarly book?—properly printed, properly bound, endurable, worthy of a very great subject.

PERFORMANCE OF A PISTON-TYPE AERO-ENGINE. A. W. Morley, Ph.D., M.Sc., A.C.G.I., Wh.Sc., A.F.R.Ae.S. Pitman. 1951. 143 pp. 43 figs. Index. 25s. net.

This monograph (to quote the author's preface) was originally written as one of a series of war records for the Director-General of Scientific Research, Ministry of Aircraft Production. During the early years of the Second World War the author was engaged on research at the Royal Aircraft Establishment into the altitude performance of piston engines. During this period, by means of high altitude plant and flight tests both at R.A.E. and by the firms, in the analysis and correlation of which the author played a leading part, the major problems of aero-engine altitude

performance were solved. Dr. Morley is therefore eminently qualified to describe the results of this work.

The book is a small one—it contains eight fairly short chapters—but is packed full of "meat," with, as befits its original purpose, not one superfluous word. Indeed on occasion, we felt that the author might have so far relaxed the austerity of his style to have enlarged a little on the more difficult or doubtful points. The book however is not intended for the general student—although he may study it with considerable advantage—but rather for the engine performance specialist and the budding project engineer to whom it must prove an invaluable reference.

Including an introduction to the subject, the first six chapters discuss the development of what has become the accepted British method of predicting the performance of a supercharged engine with a geared supercharger. In general, the procedure adopted was to deduce rational expressions based on sound fundamental principles (as for example for the Charge Weight Law) and then to test and confirm their validity against engine calibrations. The supercharger, the correction of pressure ratio from the maker's rating test, the derivation of the true rated altitude, and the pumping and friction horse power laws are discussed, and several complete performance charts are illustrated. This, the main section of the book, concludes with a discussion of intake and exhaust effects. These chapters constitute what is in effect a unique and probably final treatment of the subject, which for many years had been dealt with by applying certain empirical rules whose validity had clearly begun to break down in regard to highly-supercharged engines. One could wish, however, for the sake of completeness, that Dr. Morley had found space for at least a summary of the performance methods current at that time both in this country and abroad, as well as some discussion of the four-stroke turbo-supercharged engine.

The last two chapters, which deal with the two-stroke and the compound (complex) engine respectively, may perhaps be considered the most valuable in the book, especially by those readers to whom the simple reciprocating engine is a matter of only historical interest. The peculiar air-flow law of the two-stroke is discussed (it is hoped that future work may throw further light on this point) mainly in relation to the Rolls-Royce "Crecy" engine, and the matching problems posed by the various possible arrangements of the "complex" engine are clearly if briefly presented.

A few minor misprints were noted: on p. 66, $AT_{evap}=\theta$ should read $AT_{evap}=0$; on p. 81, Fig. 25 should be Fig. 23; on p. 87 Napier II should be Rapier II, and on page 94, $(V_a)^2/\sqrt{T_a}$ should read $(V_a/\sqrt{T_a})^2$.

Dr. Morley is to be congratulated on a most valuable little book.

WINGS FOR TOMORROW. John W. R. Taylor and Maurice F. Alwood. Ian Allen Ltd. London. 1950. 112 pp. Photographs. 7s. 6d. net.

To one who has not had much direct contact with flying boats—or seaplanes for that matter—this book has more than the usual interest of a historical review.

It has been instructive to see how "'boats"—as the authors have it—have evolved steadily from the earlier flying days up to the present, keeping more or less in step with their land bound contemporaries, sometimes being ahead in performance, and yet moving nearer and nearer their demise

For demise it seems to be, at least for civil machines in Great Britain, as with the recent announcement by the Ministry of Supply that the Princess class will be operated by the R.A.F. and not by B.O.A.C., the stage is set for landplanes on British scheduled services for many a long day to come.

The authors say in their note that the book is "intended to stoke the fires of controversy." It will certainly do this, as on the controversial ground of the economics of civil aircraft, statements are made with scarcely enough evidence to satisfy someone anxious to obtain an honest appraisal of the merits and demerits of flying boats. Leaving aside the subjective aspects which are mentioned on pages 79 and 80 in particular, the case for the flying boat would have been better served

by a more objective analysis of the operating costs, including not merely the direct costs, as determined by the S.B.A.C. formula, but also a realistic estimate of the associated overheads when a chain of flying boat bases has to be established and run on a competitive basis with landplanes.

The reviewer's impression is that the case has been over-stated as some undoubted drawbacks of flying boat operation have not been mentioned. To take one example, the application of I.L.S. to flying boat operations would be a distinct boon, as use of such an aid would enable night operations to be run just as easily with flying boats as with landplanes. The utilisation and scheduling would improve —and so would the economics.

By omitting to deal with points such as these, the authors leave themselves open to attack.

The book is at its best and it is most interesting when describing the development of the various 'boats and seaplanes built and flown, some successfully and some not, in this country over the past 40 years or so. Excellent photographs are provided of most of the basic types and a most useful chronological table of British flying boats is given. It would have been even more valuable to have had a "family tree" showing the development of each line of boats from each of the principal firms.

Interesting little points are that manufacturers nowadays no doubt wish that present day prototypes were as docile as the A. V. Roe one, which flew "almost daily without mishap throughout 1912, an incredible achievement in those days." And in any other days too! Also that British Railways (Southern Region) must be mighty proud of their trains which bring Southampton within "one hour train 'distance' from London. . .", mine usually take a lot longer than that!

HISTORY, IN THE NOT SO GRAND MANNER—NO. 5 BOMBER GROUP. W. J. Lawrence. Faber and Faber. 1951. 253 pp. Illustrated. Index. 15s. net.

Were each day in our national life identical with the preceding one, an account of the happenings of any period longer than one of 24 hours would surely be unwarranted? Since, however, no two days are the same and since the characters filling the stage and the motives actuating them are for ever changing, every field of human endeavour merits a history of its own, for it is due to the proper understanding of such records of past achievements that future progress is made.

The evolution of No. 5 Bomber Group from puny peace-time beginnings to the great striking force it became by the end of the War, gives or should give great scope to an author, coldly appreciative of the logistic, tactical and strategic problems involved, yet warmly conscious of the Homeric courage and high organising ability which their solution, of necessity, evoked.

Mr. W. J. Lawrence has chosen an inspiring subject for his historical study. He was in an especially privileged position to carry out his task, but has he succeeded in so doing? In the opinion of the reviewer he has produced a commonplace book, when he could have told a tale befitting of our finest hour.

After nearly five and a half centuries, Henry V, on the strength of a single battle gravely fought, lives on. He does this, for his historian possessed the essential genius necessary to give immortality to him and to those few, that band of brothers who fought on Crispin's day. No. 5 Bomber Group engaged in battles of greater magnitude and significance than Agincourt, yet if posterity has to depend on Mr. Lawrence for an account of them, never will the great commanders, the brave, brave fighters and the unnumbered thousands of artisans of victory be freshly remembered.

This book deals with great events. Of these, the author may well have given an accurate account, but he has done so in dull staccato sentences, in the manner of the Chairman of a Limited Liability Company addressing the Annual General Meeting of its dull, complacent shareholders. To be fair to Mr. Lawrence, he has written a painstaking book. It will be studied and rightly studied by those whose duty it is to understand the evolution of war in the air, but it will be read from cover to cover by only the most persistent members of the general public.

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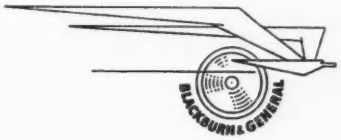

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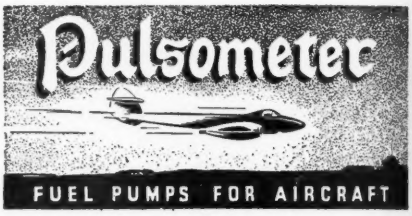

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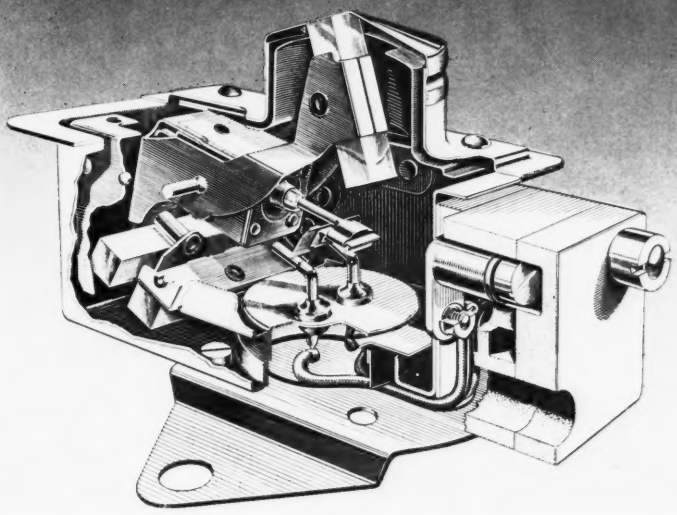

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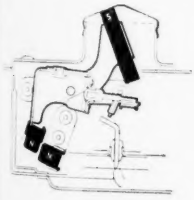

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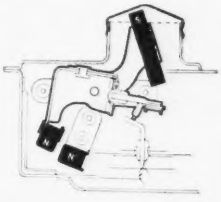

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